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[625. 145]

Railway curves.

Running over two tangent curves having the same superelevation, but different radii (*).

Tolerance for the alignment of the curves,

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In this paper it is proposed to calculate the difference between the versines of two tangent curves, so that a passenger standing in the corridor of a coach would not be subjected to any noticeable jolt when passing over the tangent point at a speed = v.

Later will be investigated how a tolerance in the alignment of curves can be determined.

When a vehicle of mass m works round a curve of radius R without superelevation, it is subjected to a centrifugal force equal to $\frac{m\,v^2}{R}$ and, in consequence, its centrifugal acceleration is equal to $\frac{v^2}{R}$, v : speed in metres per second. If the vehicle passes from a straight section on to a curve of radius R by a parabolic transition of length l, the centrifugal acceleration varies from 0 to $\frac{v^2}{R}$.

The vehicle takes $\frac{l}{v}$ seconds to run over the transition of length l.

The variation of the centrifugal acceleration in one second is thus equal to

$$\varphi = \frac{\frac{v^2}{R}}{\frac{l}{v}} = \frac{v^3}{R\,l}$$

On the other hand

$$v = \frac{V \times 1000\text{ m}}{3\,600''} = \frac{V}{3.6}$$

(*) This paper resumes and completes the article which appeared in the *Bulletin of the International Railway Congress Association* for September, 1930.

V : Speed expressed in km./h., and φ becomes :

$$\varphi = \frac{V^3}{3.6^3 R\,l} = \frac{V^3}{46.67\ R\,l}$$

To obtain the variation of the centrifugal acceleration φ_1, when a vehicle of length a crosses the tangent point of a straight section and a circle of radius R, certain German Engineers (1) assume $l = a$ in the preceding formula, which gives :

$$\varphi_1 = \frac{V^3}{46.67\ R\,a} = \frac{v^3}{Ra}.$$

Let us examine if this formula measures correctly the variation of acceleration which it is desired to calculate.

Let a curve of radius R be tangent at T to a straight section AT (fig. 1).

A passenger placed at D, midway between B and C, is subjected to the centrifugal force $\frac{m\,v^2}{2\,R}$, for the point D describes a circle of radius 2R, since

$$FD = \frac{C\ E}{2} = \frac{x^2}{2 \times 2\ R}.$$

Generally a passenger placed at n metres from B is subjected to the centrifugal force

$$\frac{m\,v^2.\,n}{R\,a}.$$

Theoretically this force is applied instantaneously to each passenger between B and C. Passengers at B and C feel abruptly the centrifugal force $\frac{m\,v^2}{R}$ on passing point T. The remaining passen-

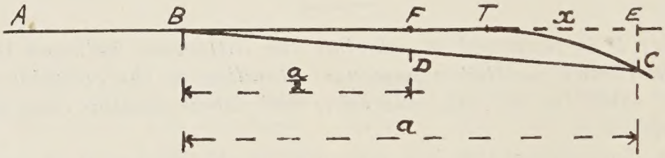

Fig. 1.

Let us assume that a vehicle of wheelbase a with two pairs of wheels BC, running first on the straight section AT, enters the curve TC of radius R at speed v.

As soon as the pair of wheels C crosses the tangent point T, every passenger who is riding over C is instantaneously subjected to the effect of the centrifugal force $\frac{m\,v^2}{R}$, whilst a passenger riding over B is not disturbed by this force, but is only subjected to the rotation of the vehicle about B, which is hardly noticeable.

gers at once feel a force equal to $\frac{m\,v^2\,n}{R\,a}$. In practice this force is not instantaneous by reason of the play which exists between the body and the wheels, and also on account of the springs.

Now let us study more closely the formula : $\frac{v^3}{R\,a}$.

This formula can be written :

$$\frac{v^3}{R\,a} = \frac{\frac{v^2}{R}}{\frac{a}{v}},$$

$\frac{a}{v}$ being the time, in seconds, taken by

(1) *Organ* of the 1st December, 1934, p. 429.

the whole vehicle to enter the curve. It actually is a variation of acceleration per second, but no passenger is subjected to it, the application of the centrifugal force

$$\frac{m\,v^2}{R} \text{ or } \frac{m\,v^2\,n}{R\,a}$$

being instantaneous or nearly so.

The formula $\varphi_1 = \frac{v^3}{R\,a} = \frac{V^3}{46.67\,R\,a}$ not corresponding to any phenomenon, cannot be used as it was by Mr. Chr. Broen Christensen, Engineer of the Danish State Railways, in the *Organan*, No. 19, October, 1937, for calculating the variation φ_2 of the centrifugal acceleration or the lurching brought about by a vehicle with a 17.40-m. (57 ft. 1 in.) wheel base which passes rapidly and directly from a straight alignment to a curve having a radius of 3 000 m. (150 chains) (1). This lurching cannot be calculated; to ascertain its value it must be measured. There is nothing in common, moreover, between the crossing, at high speed, of the tangent point of a straight section and a curve, and the running on a long parabolic transition at the same speed.

The variation of the acceleration φ_2 due to the first phenomenon cannot be compared with the variation φ due to the second. The first is abrupt, theoretically instantaneous, but in practice it is produced in a very short time (2). The second is a continuous variation.

The crossing of the tangent point of two curves having different radii is an analogous case to that of crossing the tangent point of a straight section and a curve.

(1) $\varphi_1 \frac{\overline{120}^3}{46.67 \times 3\,000 \times 17.40} = 0.71.$

(2) This time depends upon the type of vehicle. It is approximately 1/20 of a second for large bogie coaches.

In consequence, to determine the difference between the radii of two curves which must follow each other, the superelevation remaining constant, so that a passenger standing in a corridor would feel no jolt, the variation φ_2 must be taken as basis.

The problem then consists of finding, with the help of accelerometers, the value of the lurching which has no effect on a passenger standing in a corridor and to equate this value to a function of the difference $\frac{v^2}{R_1} - \frac{v^2}{R_2}$

between the accelerations to which the same passenger will be subjected when he passes, at speed v, the tangent point of the curves having radii R_1 and R_2.

We must, therefore, have :

$$\varphi_2 = C\,v^2\left(\frac{1}{R_1} - \frac{1}{R_2}\right).$$

The lurching when passing, at speed v, the tangent point of a straight section with a curve having a radius ρ is greater than the acceleration $\frac{v^2}{\rho}$ because of the « shock on entering the curve ». It can be likened to :

$$C_1\,\frac{v^2}{\rho},\; C_1 > 1.$$

If we take this lurching as basis for the calculation of the difference between the radii R_1 and R_2, which can follow each other, in the main part of the curve, we shall have :

$$\varphi_2 = \frac{C_1\,v^2}{\rho} = C\left(\frac{1}{R_1} - \frac{1}{R_2}\right)v^2.$$

On the other hand, it is evident that the increase in the accelerations due to

the « shock on entering the curve », is the same in both cases; therefore :

$$C = C_1 \text{ and } \frac{v^2}{\rho} = \left(\frac{1}{R_1} - \frac{1}{R_2}\right) v^2.$$

Experience shows, however, that a curve of 2 500 m. (125 chains) radius is entered without noticeable shock at a speed of 95 km. (59 miles) per hour (v = 26 m. = 85.3 ft.) the superelevation at the tangent point being equal to :

$$\frac{1}{2} \times \frac{75}{2\,500} = 0.015.$$

In this case the centrifugal acceleration is equal to :

$$\varphi_2 = \frac{\overline{26}^2}{2\,500} - \frac{9.81 \times 0.015}{1.50} = 0.172$$

(1.50 m. being the track gauge).

In the middle part of the curve, the centrifugal acceleration, due to the difference in curvature, will be :

$$v^2 \left(\frac{1}{R_1} - \frac{1}{R_2}\right).$$

We must have, therefore :

$$v^2 \left(\frac{1}{R_1} - \frac{1}{R_2}\right) = 0.172.$$

The multiplication of the two terms by $\frac{a^2}{2}$, a being the equidistance between the pegs of the curve, gives :

$$v^2 \times \frac{a^2}{2} \left(\frac{1}{R_1} - \frac{1}{R_2}\right) = 0.172 \frac{a^2}{2}$$

and :

$$v^2 (f_1 - f_2) = 0.172 \frac{a^2}{2};$$

for a = 10 m.

$$f_1 - f_2 = \frac{0.172 \times 50}{v^2} = \frac{8.6}{v^2}.$$

Thus for V = 120 km. (75 miles) (v = 33 m. = 108 ft.), we have $f_1 - f_2$ = 8 mm. (0.315 in.) and a curve travelled over at this speed can be composed of several arcs, the difference between the versines of which being 8 mm. (0.315 in.).

In order that the superelevation may remain constant it is necessary that these differences follow each other as shown in figure 2

But what is the minimum distance possible between the tangent points of these circular arcs ?

A priori we think that their minimum spacing can be taken as equal to the distance covered during the damping out of an oscillation of the spring-borne body of the vehicle.

When V = 120 km. (75 miles) (v = 33 m. = 108 ft.), the period of the damping out of an oscillation being 1.5 seconds, the minimum distance apart of the tangent points will be 33 × 1.5 = 50 m. (164 ft.).

These rules greatly facilitate the correction of badly shaped curves, and they allow of very good alignments being obtained with little shifting of the track.

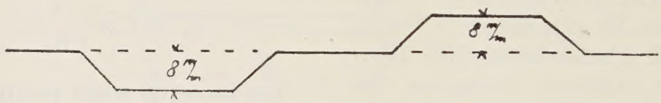

Fig. 2.

Can it, however, be concluded from this that the successive versines of a circular curve can vary 8 mm. (0.315 in.) from the value of the theoretical versine of this curve, as shown in figure 3, and thus fix a sort of tolerance for the adjustment of curves ?

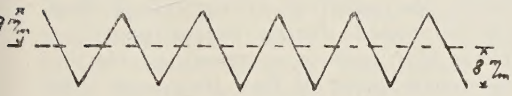

Fig. 3.

We do not think so, experience alone being able to answer such a question because of the number of factors brought into play.

This tolerance will be determined in the following manner. A circular layout would be brought into being, having a constant superelevation, but so deformed that the successive versines, which differ by 16 mm. (0.63 in.) oscillate like the teeth of a saw about the theoretical value of the versine of the circular arc. These versines would be recorded, for checking purposes, with the machine described by Messrs. Lanos and Leguille, in an article in the *Revue Générale des Chemins de fer* of 1st December, 1937.

Then, at the speed of 120 km. (75 miles) an hour, the lateral accelerations will be measured with the Mauzin-Langevin piezo-electric quartz apparatus.

Arcs of circles having different radii will be taken for the experiment.

If the accelerations measured have no influence on a standing passenger, tests will be carried out with greater differences between the versines, and thus the tolerance sought will be determined. Besides, the comparison of the diagrams of versines and the superelevations obtained with the above mentioned machine on tracks under service conditions, with acceleration diagrams measured at high speed on these tracks, will enable admissible tolerances to be fixed.

However, in tolerance matters, one should be very careful. It is necessary, before adopting definite rules, to ensure, by successive measurements, that the small deformations thus allowed cannot be the cause of larger deformations affecting the comfort of passengers. It is, of course, understood that when laying or maintaining curved tracks they must always be correctly « pegged », there being no reason to allow for faults in alignment.

[625. 143.2 (.42)]

Reproducing the wearing qualities of early steel rails under modern conditions (*),

(*The Railway Gazette.*)

The paper describes three stages by which the physical properties of steel rails in Great Britain have been materially improved during recent years — the substitution of a medium manganese for a high carbon composition, the introduction of controlled cooling, and the development of heat treatment. The average figures in this paper showing the respective effect on the tests of increased manganese and of controlled cooling are the first of their kind to be published.

Some years ago it was a commonly expressed criticism in Great Britain that the rails then being manufactured were inferior in their wearing capacity to the rails produced in the earliest days of steelmaking. It was realised that the inferiority of the latter product could not be explained entirely by the great increase in the weight, speed, and frequency of the trains that had taken place in the interim. The early rails had the advantage of lower rolling temperatures, and especially of lower finishing temperatures, which meant a very gradual reduction of the ingot during rolling; on the other hand, their content of sulphur and phosphorus was high, in comparison with present standards, and the carbon was generally low. In 1931 the Southern Area of the London & North Eastern Railway conducted an investigation into the chemical and physical properties of certain rails which had been continually in use from 42 to 51 years in secondary tracks (the results of which were set out in an article in the January, 1932, issue of *The Railway Engineer* by Mr. R. J. M. Inglis, then Permanent Way Engineer, Southern Area, L. N. E. R.). Of these rails the most noteworthy feature was found to be a hardening of the running surface; and the conclusion reached was that when these rails were laid, they were sufficiently in advance of the traffic conditions of their time to work-harden on the running surface, and this work-hardening provided a valuable protection against abrasive wear in the later years of their life, when the traffic was becoming heavier and faster. The principal lessons of the research were that the later trend in rail manufacture towards higher carbon percentages, and lower sulphur, phosphorus, and manganese, had been without justification from the rail wear point of view; also that the type of rail now to be sought was one still sufficiently in advance of present-day traffic conditions to be similarly capable of work-hardening in the earlier years of its life. But even if the early steel compositions could be reproduced, with modern methods of steelmaking, it is doubtful if they would stand up to the physical tests now demanded, and to the falling weight test in particular, if modern mill practice were followed in rolling the rails, while

(*) Summary of a paper entitled « The exceptional wearing properties of early steel rails and their reproduction in modern rail manufacturing conditions », by Mr. Cecil J. Allen, technical assistant, Engineer's Department, Southern Area, L.N.E.R. It was presented and discussed on September 21, at the Fourth International Rail Congress at Düsseldorf.

to restore, in these days of mass production, the rolling temperatures and the work done on the steel in earlier days, might quite conceivably prove a remedy more costly than the disease of unduly rapid wear which it is sought to cure.

These conclusions had been supported by the experience of the L. N. E .R. with steel rails made to the British Standard Specification for Rails of 1922. Owing to the almost complete substitution in Great Britain of open-hearth basic for Bessemer acid rail steel production after the war period of 1914-1918, the change was utilised to specify a steel containing 0.55 to 0.65 per cent. of carbon instead of the previous limits of 0.35 to 0.50 per cent., but with severely limited sulphur and phosphorus (0.05 and 0.04 per cent. maximum respectively with basic open-hearth steel), and manganese restricted to a maximum of 0.80 per cent. in order to avoid the brittleness that might be caused by an unduly high combination of carbon and manganese. Although considerably harder than before, these rails, with the additional disadvantage of high modern rolling and finishing temperatures, were found to have a coarsely crystalline structure that tended to grind or powder away under traffic, and it was on their inadequate wearing capacity that the criticism of past versus present has doubtless been chiefly based.

In 1931 the London & North Eastern Railway, after experiments on the Southern Area which showed in particular the loss of wearing capacity which had been experienced by cutting down the manganese percentage, introduced a new rail specification in which the carbon, in the open-hearth basic process, was reduced to limits of 0.50 to 0.60 per cent., but manganese was increased, a minimum of 0.90 per cent. being demanded, with a maximum of 1.10 per cent., since increased to 1.20 per cent. These limits of 0.90 to 1.20 per cent. of manganese were also standardised in the British Standard Specification for rails of 1935, which is now in general use by British railways. The maximum limits of sulphur and phosphorus were also relaxed on the L. N. E. R. Southern Area to 0.06 per cent., it being hoped that the slight increase in the phosphorus percentage might prove of some assistance to wear. It was anticipated, further, that the increased percentage of manganese, in view of the well-known properties of that element in « healing » the rolled surface of the steel, would give a better finish, and so reduce the rejections of the rails for skin defects, and this has proved in practice to be a correct forecast.

In Table A details are given of the improvement in physical properties of the rail steel that has resulted from the change-over from high carbon to medium manganese composition. While the average breaking strength of the steel has been maintained or slightly increased, the elongations and reductions of area, giving evidence of the relative toughness of the steel, have increased considerably, and the beneficial effect of the manganese is evident in the improved microstructures of these rails. In this table, analyses and tests have been averaged over considerable tonnages of rails, with no omissions, and therefore fairly represent normal practice, rather than a selection merely of the best results. From this table it will be seen that, as a result of increasing manganese from an average of 0.70 to 1.05 and 1.02 per cent., and lowering carbon from 0.61 to 0.55 and 0.56 per cent., the breaking strength of the steel has moved up from 51.9 to 52.7 tons per sq. in., and at the same time the elongation has increased from 13.4 to 17.0 and 18.0 per cent., and the reduction of area from 17.1 to 28.3 and 29.2 per cent. The British Standard Specification is satisfied with a minimum elongation of 10 per cent.

The second step towards improved

TABLE A. — Comparison of average compositions and physical tests of L. N. E. R. steel rails, showing the effect of a change from a high carbon to a medium manganese analysis.

Rails, 95 lb. and 85 lb. per yard (47.5 and 42.5 kgr. per m.), bull-head section, rolled from open-hearth basic steel by the Shelton Iron, Steel, & Coal Co. Ltd.

Year of manufacture.	No. of casts.	Total weight of rails.	Average chemical composition.					Average tensile test results.			
			C	Si	S	P	Mn	Breaking strength.		Elongation.	Reduction of area.
		Tons.	%	%	%	%	%	T./in².	Kg./mm².	%	%
(*) 1930. . .	51	2 500	0.61	0.125	0.042	0.041	0.70	51.9	81.7	13.4	17.1
(*) 1937. . .	12	500	0.55	0.135	0.051	0.044	1.05	52.7	83.0	17.0	28.3
(†) 1938. . .	45	2 000	0.56	0.132	0.038	0.038	1.02	52.7	83.0	18.0	29.2

(*) 95-lb. section. (†) 85-lb. section.

quality has been one devised in the first instance as a safety precaution rather than to increase wear resistance; this is the method of controlled or retarded cooling devised by Messrs. Sandberg, the British consulting engineers, as a protection against the development in the rail-head during cooling of stresses sufficiently severe to produce shatter-cracking. In some degree such stress-formation always takes place during the normal cooling of rails on a hot-bank, but it is accentuated by any more rapid form of cooling through the critical range of temperature, as, for example, when the rails are sorbitically treated in the manner referred to later; it was partly in the interests of their sorbitic treatment, and partly because of the serious internal fissure problem in America and elsewhere, that the protective cover for the controlled cooling of rails, known as the Sandberg oven, was devised.

The stresses to which reference has been made are the direct result of the differences in the rate of cooling of the head, web, and foot of the rail, as well as of the difference in temperature between the outside and inside of the rail-head during cooling; and it is to avoid this stress-formation that the cooling of the rails is retarded. At certain works the Sandberg ovens are fixed chambers, but the latest type of oven is a moving cover of high efficiency; in either case the rails are slowly traversed by skids through the oven, entering it at about 500° C. In the oven the temperature throughout the whole of the rail first becomes uniform, and the rails are then allowed to cool, at such a rate that no substantial temperature difference is set up, down to about 300° C., after which they are passed out into the open air to cool down to atmospheric temperature.

The Southern Area of the L. N. E. R. was one of the first users in Great Britain to specify controlled cooling for all its rails, and Table B witnesses to the considerable influence that the combin-

Rails, 95 lb. per yard (47.5 kgr. per m.), bull-head section.

Year of manufacture.	No. of casts.	Total weight of rails.	Average chemical composition. C	Si	S	P	Mn	Average tensile test results. Breaking strength.		Elongation.	Reduction of area
		Tons.	%	%	%	%	%	T./in².	Kg./mm².	%	%
Bessemer acid rails, United Steel Companies Ltd., Workington.											
1920	90	1 500	0.53	0.125	0.045	0.057	0.77	50.1	78.9	16.8	24.8
1937	95	2 000	0.49	0.130	0.042	0.052	1.13	51.9	81.7	20.3	34.8
Open-hearth basic rails, Cargo Fleet Co. Ltd.											
1920	29	1 500	0.56	0.099	0.053	0.041	0.80	50.3	79.2	14.8	19.5
1937	54	2 500	0.56	0.112	0.035	0.036	1.11	53.6	84.4	18.0	29.0
Open-hearth basic rails, Lancashire Steel Corporation Ltd.											
1926	32	1 500	0.61	0.131	0.040	0.034	0.73	52.3	82.4	15.4	24.4
1938	71	3 500	0.56	0.164	0.035	0.031	1.12	53.4	84.1	18.5	36.2

ation of medium manganese composition and controlled cooling has had on the physical properties of the steel; it shows the breaking strength, elongation, and reduction of area of rail steel, before and after the change, at three different rail-mills, averaged over considerable tonnages of rails for the L. N. E. R. Southern Area, again including every cast without omission in each batch of rails. The falling weight tests alone have been omitted, as these throughout were satisfactory, and the results do not offer so instructive a basis of comparison as the tensile tests.

With the Bessemer acid rails, in which carbon was reduced by an average of 0.04 per cent. (from 0.53 to 0.49 per cent.), while manganese was raised from 0.77 to 1.13 per cent. (by 0.36 per cent.), tensile strength has been raised from 50.1 to 51.9 tons per sq. in., and at the same time the elongation has risen from 16.8 to the remarkable average figure of 20.3 per cent., and reduction of area from 24.8 to 34.8 per cent. In one of the open-hearth basic comparisons the effect is seen of maintaining the average carbon constant at 0.56 per cent., but raising the manganese from 0.80 to 1.11 per cent.; this increased the average breaking strength from 50.3 to 53.6 tons per sq. in., but at the same time the average elongation has risen from 14.8 to 18.0 per cent., and the average reduction of area from 19.5 to 29.0 per cent. In the other open-hearth basic comparison, the average carbon has been reduced from 0.61 to 0.56 per cent., and the average manganese has been raised by as much as 0.39 per cent (from 0.73 to 1.12 per cent.), and the result has been to add slightly to the breaking strength, from 52.3 to 53.4 tons per sq. in., while the elongation has gone up from 15.4 to 18.5 per cent., and the reduction of area from 24.4 to the high average of 36.2 per cent.

In Table C a further comparison is made between medium manganese rails

TABLE C. — **Comparison of average compositions and physical tests of L. N. E. R. steel rails, showing the properties of medium manganese rails without and with controlled cooling.**

Rails, 95 lb. per yard (47.5 kgr. per m.), bull-head section, rolled from open-hearth basic steel by the Lancashire Steel Corporation Ltd.

Year of manufacture.	No. of casts.	Total weight of rails.	Average chemical composition. C	Si	S	P	Mn	Average tensile test results. Breaking strength.		Elongation.	Reduction of area.
		Tons.	%	%	%	%	%	T./in².	Kg./mm².	%	%
1929	10	500	0.56	0.137	0.029	0.033	0.99	53.0	83.5	16.0	25.1
1938	71	3 500	0.56	0.164	0.035	0.031	1.12	53.4	84.1	18.5	36.2

manufactured before controlled cooling had become a standard requirement of the London & North Eastern Railway, and the present standard rail. The average compositions are similar, save that in the later rails the manganese is 0.13 per cent. higher; it will be seen that a slightly higher average breaking strength is accompanied by an increase in elongation from 16.0 to 18.5 per cent., and in reduction of area from 25.1 to 36.2 per cent. Subsequent tests that have been made at other works where at the present time medium manganese rails are being manufactured both with and without retarded cooling fully confirm the advantages in increased elongation and reduction of area that are obtained when the control of cooling is operative.

It may be mentioned here that in 1934 an experiment was made by the Southern Area of the London & North Eastern Railway with a still higher content of manganese, 500 tons being manufactured with an average manganese percentage of 1.52 per cent., carbon being reduced to an average of 0.49 per cent. The physical tests were slightly superior to any of those yet described, and as a matter of interest they were compared in Table D with the tests on 2 000 tons of « Plough » steel (high carbon-low manganese) rails rolled in 1929. Although the breaking strengths of the two varieties were roughly equal, the higher manganese rails showed an average elongation of 18.7 per cent. as compared with the 12.8 per cent. of the « Plough » steel rails, while the reduction of area of the former averaged no less than 38.7 per cent., or more than double the 18.2 per cent. of the latter. The higher manganese rails have given good service, but the difference in wearing capacity is not regarded as sufficient to justify a change from the standard medium manganese rail to the higher manganese quality.

On the other hand, track wear tests have proved that, as compared with the

TABLE D. — Comparison of average compositions and physical tests of L. N. E. R. « Plough » steel (low manganese-high carbon) and high manganese (1.50 per cent.), low carbon rails open-hearth basic quality.

Rails, 95 lb. per yard (47.5 kgr. per m.), bull-head section.

Type of steel.	No. of casts.	Total weight of rails.	Average chemical composition.					Average tensile test results.			
			C	Si	S	P	Mn	Breaking strength.		Elongation.	Reduction of area.
		Tons.	%	%	%	%	%	T./in².	Kg./mm².	%	%
Plough . . .	37	2 000	0.69	0.060	0.030	0.033	0.69	55.1	86.8	12.8	18.2
Manganese . .	9	500	0.49	0.164	0.027	0.034	1.52	54.5	85.8	18.7	38.7

previous standard high carbon rail, the present standard medium manganese rail has an increased life of 25 to 33 per cent. To this life controlled cooling is now indirectly adding, for by the relief that it affords of harmful stresses in the rail-head, it has permitted higher combined percentages of carbon and manganese in the rails, the increased hardness so secured being combined with increased toughness, of which ample evidence is given by the elongation and reduction of area percentages just quoted. With British railways retarded cooling of all rails is now a standard requirement in the case of all the rail-mills which have installed the Sandberg oven for its application; the large majority of British rail manufacturers are now so equipped.

If the recognition of the value of manganese as a wear-resisting element in the steel be regarded as a first step towards the restoration of a work-hardening quality, and controlled cooling both as an accessory and as a safeguard in taking a longer step in that direction than might otherwise have been safely possible, the next step is that of producing, if possible, a rail sufficiently in advance of present-day traffic conditions to have some chance of work-hardening and so of prolonging its life. The possibility of doing some cold rolling on the rail-head before the rails left the works and are laid in the track, by installing some description of mill for this purpose, has been examined, but the difficulties were too great to make it practicable for the idea to be carried out, even experimentally, at any reasonable cost. A suggestion along the same lines was made in a contribution by a Russian engineer, Professor P. Sakharow, to the *Proceedings* of the Second International Rail Congress at Zurich in 1932, his proposal being that new rails should undergo preliminary service in secondary lines, in which the traffic is light, and thus — assuming that the rails are of suitable

composition and physical properties to be capable of work-hardening — provide themselves with a protective skin on the upper surface before their maximum service conditions began. A considerable amount of experiment would be necessary, however, to show whether or not the increased life so obtained would be adequate compensation for the cost of the additional track-laying operations involved.

The need for a hard-wearing rail is, of course, the most acute in the case of tracks over which traffic conditions are exceptionally severe, such as lines carrying electrified suburban services, or those with heavy traffic over steep gradients and sharp curves, or switches and crossings. As in other countries, two lines of approach to this problem have been tried in Great Britain, one by the use of alloys and the other by heat treatment. The type of steel which has probably shown a greater capacity for work-hardening than any other is manganese alloy containing from 12 to 14 per cent. of manganese, but in Great Britain its extremely high cost has only justified its use in locations (chiefly complicated junction work) where the wear is altogether exceptional and traffic conditions make frequent renewals of ordinary rails a troublesome business; for this reason the use of manganese alloy rails in Great Britain does not extend, and is chiefly confined to electric lines. Another steel alloy which has been used to some extent is chromium, in percentages varying from 0.5 to 1.0 per cent., but again the use does not increase, partly because of the somewhat uncertain properties of this class of steel, arising out of the critical temperature control needed in manufacture, particularly in cooling; and partly because better wear results are now being obtained at a lower cost with heat-treated rails of standard chemical composition.

So far as concerns Great Britain, only one type of heat treatment for rails has become established, but the present indications are that this will shortly be a standard requirement of British railways for all rail renewals in locations where the life of rails is relatively short. This is the Sandberg regulated sorbitic process, for which there are now treatment plants at five different rail mills. The Southern Railway, which has the largest electrified suburban railway system in the world, and, consequently, very severe rail wear conditions, has now for some years past been laying in the track over 10 000 tons of regulated sorbitic rails annually; orders on a considerable scale have been placed this year by the London Midland & Scottish and London & North Eastern Railways as first instalments of what will in future be an annual requirement of sorbitic rails; and a future annual output of at least 20 000 to 25 000 tons of this quality for British railways alone, apart from export orders, may be regarded as probable.

The latest methods of applying the Sandberg sorbitic treatment were described in detail and illustrated in the January 10, 1936, issue of *The Railway Gazette*. The actual treatment consists in the application to the railhead, immediately after rolling, under very exact pyrometric control, of a finely atomised spray of water under pressure, special measures being taken to ensure perfectly even atomisation of the spray, and to regulate the treatment according to the chemical composition of the cast of steel concerned. The sorbitic treatment is followed by counter-cambering of the rail in a special cambering machine, to reduce to a minimum the amount of cold-straightening necessary, and then by controlled cooling.

The outstanding characteristic of the regulated sorbitic rail is the rise that takes place, in the heated area of the head, in the yield point of the steel, which proportionately is far greater

than the rise in the breaking strength. Whereas the breaking strength of a tensile test cut with its centre-line 3/8-in. below the running surface of the rail normally rises about 20 per cent. as a result of the treatment, the yield point may be relied on to rise by 60 per cent. or over. Compression tests that have been made upon small cylinders of steel cut from the head of sorbitically treated rails, and shaped to a diameter of 1/2 in. and 1 in., have shown the same characteristics of an exceptionally high yield point when compared with similar cylinders cut from untreated rails. The depth of penetration of the treatment extends to well below the maximum depth to which the rail-head would be allowed to wear in the course of ordinary service; even at 5/8-in. below the running surface, the structure of the rail is almost entirely sorbitic. In order to demonstrate the freedom of the treated steel from any shatter-cracking or brittleness as a result of the quenching treatment, the sorbitic rails are subjected to the falling weight test head downwards, so that the steel of the head is in ten-

TABLE E. — Average analyses and physical tests of regulated sorbitic rails for the London and North Eastern Railway, 100-lb., 95-lb., and 85-lb. per yard bull-head sections.

Rolled by the United Steel Companies Ltd., Workington, from Bessemer acid steel.

Section of rail.	No. of tests.	Chemical analysis. Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.
		%	%	%	%	%
100 lb.	6	0.50	0.110	0.043	0.037	1.09
95 lb. (1)	4	0.49	0.114	0.046	0.041	1.19
85 lb.	7	0.49	0.133	0.039	0.038	1.10
95 lb. (2)	5	0.49	0.144	0.037	0.051	1.18

Section of rail.	Tensile test results. Yield point.		Breaking strength.		Elongation.	Reduction of area.
	T./in².	Kg./mm².	T./in².	Kg./mm².	%	%
100 lb. untreated	28.2	44.4	50.2	79.1	17.5	26.8
100 lb. treated	44.9	70.7	62.6	98.6	14.1	26.4
95 lb. untreated (1)	25.8	40.6	51.7	81.4	20.0	34.0
95 lb. treated (1)	44.2	69.6	63.3	99.7	14.4	30.0
85 lb. untreated	28.9	45.5	52.2	82.2	19.2	32.6
85 lb. treated	44.9	70.7	62.0	97.7	15.9	31.5
95 lb. untreated (2)	30.5	48.0	53.4	84.1	18.8	31.5
95 lb. treated (2)	52.7	83.0	64.6	101.7	14.5	28.4

sion, and in this position the customary 7 ft. and 20 ft. blows of a 1-ton falling weight test must be sustained without fracture of the test-piece. For information it is the general practice to give a second 20-ft. blow, which is almost invariably sustained by sorbitic rails without fracture.

Owing to the accurate control of the regulated sorbitic process, it is possible to level up steel of differing chemical compositions to one common standard of physical properties, and it is the reliability and consistency of the results obtained that have been one of the best commendations of this heat treatment to British railway engineers. In Table E there are summarised, in a form similar to the previous summaries, the results of a series of tests on various batches of sorbitic rails, for the L. N. E. R. Southern Area, and here again the whole of the tests made have been included without exception. It is now possible to rely on obtaining a yield point not less than 40 tons per sq. in., while elongations average over 14 per cent. and reductions of area over 30 per cent. The last batch of rails showed the best average results yet; the average yield point was 52.7 tons per sq. in., the average breaking strength 64.6 tons per sq. in., the average elongation 14.5 per cent., and the average reduction of area 29.1 per cent., and all with tensile tests of 0.564 in. diameter cut with their centre-lines 5/8 in. below the running surface of the rails.

In its combination of hardness with toughness, as expressed by the exceptional proportion of yield point to breaking strength, the Sandberg regulated sorbitic rail may therefore be expected to offer good resistance to abrasion, and the correspondingly high yield point in the compression tests indicates equal resistance to battering tendencies under the rolling load. These anticipations have been fulfilled in wear tests which have been made by the Southern Area of the London & North Eastern Railway, which have been sufficient to decide future policy by the decision to use sorbitically treated rails in all tracks which are to carry electric trains in future, or in tracks laid hitherto with ordinary rails which have had a shorter life than ten years, as well as extensively in switch and crossing renewals. One wear test in the open, from the most recent batch of regulated sorbitic rails, has to the present time shown a loss of weight by wear which averages per annum roughly one-half that of the last previous rails in the same location.

From the decision just referred to rails in tunnels are excepted, as it has been proved by experiment that the sorbitic structure offers no additional resistance where severe corrosion is a factor determining the effective life of a rail. As yet the problem of rails in tunnels in which corrosion is severe — especially tunnels in which the sulphur constituent from the exhaust of steam locomotives combines with moisture to form weak sulphuric acid — cannot be said to have reached a satisfactory solution in Great Britain. After lengthy experiments in one of the worst tunnels on the Southern Area of the London & North Eastern Railway, in which both copper and chrome have been used in varying ways for alloying the steel, in conjunction also with higher percentages of manganese, the decision has been reached that for the present the most satisfactory method of prolonging the life of the rails in at least some degree is that of painting, the precise method of which is still under consideration.

Table F, in conclusion, compares the compositions and physical properties of chromium and sorbitic rails that have been used on the L. N. E. R. Southern Area. The sorbitic tests are seen to be superior, and this superiority has been confirmed by wear tests; further, the greater consistency in the physical properties of the sorbitic rail, and its

TABLE F. — **Comparison of average analyses and physical tests of L. N. E. R. chromium and regulated sorbitic rails, 95-lb. per yard, bull-head section.**

Total weight.	No. of casts.	Average chemical composition.						Average tensile test results.			
		C	Si	S	P	Mn	Chr	Breaking strength.		Elongation.	Reduction of area.
Tons.		%	%	%	%	%	%	T./in².	Kg./mm².	%	%
* 1 000	28	0.51	0.207	0.044	0.040	0.86	0.96	60.4	95.1	12.7	25.7
† 1 000	22	0.49	0.127	0.041	0.042	1.14	—	63.1	99.4	14.7	28.3
• 200	6	0.55	0.166	0.038	0.028	1.18	—	62.5	98.5	16.3	37.7

(*) Chromium steel rails, open-hearth acid quality.
(†) Regulated sorbitic steel rails, Bessemer acid quality.
(•) Regulated sorbitic steel rails, open-hearth basic quality.

greater reliability, have to be taken into account. The 200 tons of open-hearth basic rails included in this table were a batch manufactured recently by the Lancashire Steel Corporation Ltd., and the tests were notable in that while the average elongation dropped slightly from 18.4 to 16.3 per cent., the average reduction of area rose from 33.3 to 37.7 per cent. — a figure nearly 50 per cent. greater than that obtained with the chromium rails. There is last of all the fact that the sorbitic treatment adds only from 12 to 15 per cent. (according to the tonnage ordered at one time) to the initial cost of the rails, whereas the addition for a 1.0 per cent. chromium composition is 20 per cent.

As in other countries, so in Great Britain the punishment to which the steel rail is subjected in main lines becomes progressively and rapidly more severe. Some of the fastest British express trains run over the London and North Eastern Railway; whereas at the beginning of 1932 the fastest schedule on the Southern Area of the L. N. E. R. was one of 57.6 m.p.h. from start to stop, by 1938 this speed has risen to the 71.9 m.p.h. of the streamlined Coronation express from London to York. Maximum speeds seldom greatly exceeded 80 m.p.h. in 1932; now 90 miles per hour is commonly reached by the principal express trains, and with the streamlined trains, despite operation by steam, 100 m.p.h. is not infrequently attained. With these much higher speeds locomotive weights are steadily mounting; a large number of the express passenger and freight locomotives of the L. N. E. R. now carry from 60 to 66 tons on their three coupled axles, and locomotives weighing from 92 to 104 tons without their tenders, and 148 to 162 tons with their tenders, are used in considerable numbers. So far from attempting to reproduce the lengthy life in the track of the early rails, therefore, the permanent way engineer of today finds it no easy task

even to keep pace with the effect of these increasing stresses, let alone to outstrip them.

In endeavouring to meet these conditions, and with the valuable evidence obtained from the characteristics of the early rails whose excellent wear attracted attention in the past, the Southern Area of the L. N. E. R. has proceeded by logical stages. For general use, the high carbon rail has been changed to the medium managanese rail with controlled cooling as the standard, and without any additional cost; while for those sections of the track which carry the heaviest traffic the standard medium manganese rail is subjected to the sorbitic treatment, as a decisive step, at a moderate additional cost, in the direction of a rail which is capable in at least some measure of prolonging its life by work-hardening.

In conclusion, the author of the paper expressed indebtedness to Mr. R. J. M. Inglis, Engineer, Southern Area, London and North Eastern Railway, under whose direction this research has been carried on, for permission to publish the results.

[**621**. 392 (.75) & **625**. 143.4 (.75)]

The Sperry rail-welding equipment.

(*Engineering*.)

In the February 11, 1938, number of *Engineering* (1), we illustrated and described a portable electric rail-welding plant used by the London Passenger Transport Board for welding both the running and conductor rails on their system. Welding is employed, in this case, mainly with the object of reducing the noise in the tunnel sections of the system. The rails are rolled in 60-ft. lengths, the running rails weighing 95 lb. per yard and the conductor rails 150 lb. per yard, their cross-sectional areas being 12 sq. in. and 15 sq. in., respectively. In the case of the running rails used in the tunnel sections, five lengths are welded together to form 300-ft. lengths, while the conductor rails are welded to form continuous lengths up to 240 ft. The estimated noise reduction resulting from the use of welded rails in the tubes is given as 60 per cent. Several other advantages are claimed for rail welding, of which we may mention the following: Maintenance of joints and track is reduced; the life of the rails is increased by the avoidance of impact; smoother running and reduced maintenance of rolling stock are secured; rail creep is avoided; and bonding is reduced or eliminated when track circuiting is employed. It is not surprising, therefore, that considerable attention has been given to the subject by railway engineers throughout the world, and this will be evident from three reports presented to, and discussed at, the International Railway Congress, held in Paris last year, and dealt with on pages 96, 612 and 699 of our 143rd volume (1937) (2).

As much of the work done so far has been carried out in the United States, it will be of interest to give an account of the rail-welding equipment which has been developed in that country by Messrs. Sperry Products, Inc., Manhattan Bridge Plaza, Brooklyn, N. Y., U. S. A., in conjunction with the Delaware and

(1) See also *Bulletin of the Railway Congress*, August 1938.

(2) See *Bulletin of the Railway Congress*, November, 1936, and May, 1937.

Fig. 1. — Welding equipment train.

Hudson Railroad Corporation and Messrs. The General Electric Company, Schenectady, N. Y. The flash-butt welding process is employed and the complete equipment is mounted on a train having a sufficient number of vehicles to accommodate the lengths of welded rail. The train is illustrated by the photograph reproduced in figure 1. Next to the locomotive is a box car, in which there are two turbo-generators, supplied with steam from the locomotive, one generating alternating current for use in the welder and the other direct current for various auxiliary purposes. The next vehicle in the train is a box car used as an office for the operating staff, and following this is an open rack car, the duty of which is to carry a supply of rails in 39-ft. lengths and feed them to the welding machine, which is mounted in an adjacent box car. A photograph of the rack car is reproduced in figure 2, and from this it will be seen that the lengths of rails are stored on a ramp from which they are automatically lowered on to a set of power-driven rollers, which run them along into the welder car seen in the background in figure 2.

The welding operation is shown in progress in figure 3. The adjacent ends of two rails are clamped in the welder, one clamp being fixed and the other movable. Current is supplied to each rail through clamps connected to the low-voltage secondary of a transformer, the primary of which receives current from the generator through flexible leads. The ends of the rails are brought together intermittently and the short-circuit current which flows effectively preheats the rail ends. In the next operation, known as flashing, the rail ends are kept in contact for a short time to burn off any high spots and heat the rail ends to a welding temperature. They are then brought together under great pressure, which is sufficient to squeeze out the molten metal and to form an effective weld between the plastic faces. It should be mentioned that the welding machine is hydraulically operated and automatically controlled. Once the initial adjustments have been made as a result of preliminary tests, the various operations are carried out automatically, thus ensuring complete uniformity.

The welded rail passes straight from the welding machine into the annealing furnace, shown in figure 4, the furnace being mounted on the following car and the joint remaining in it while the next

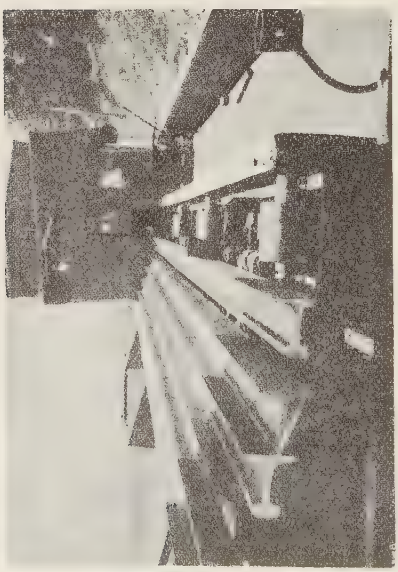

Fig. 2. — Rack car feeding rails to welder.

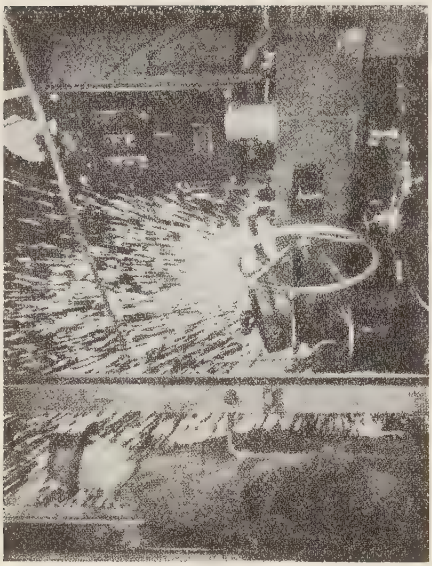

Fig. 3. — Welding machine in operation.

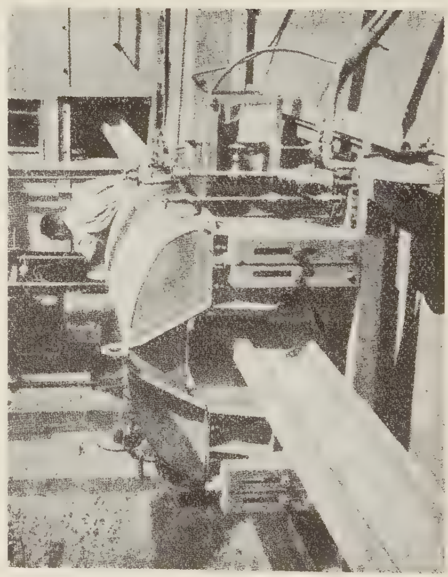

Fig. 4. — Annealing furnace.

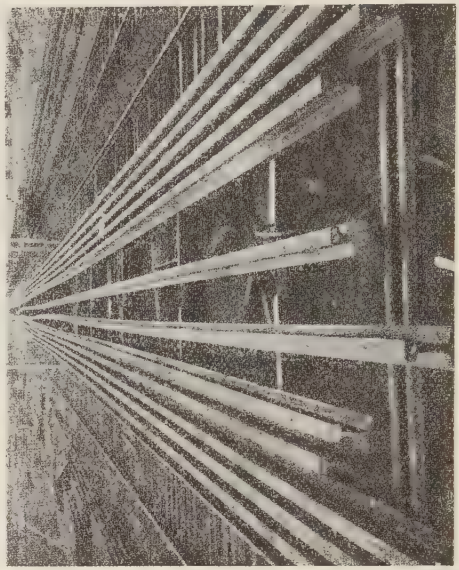

Fig. 5. — Welded rails on flat cars for transport.

weld is being made. This heat-treatment serves to relieve any internal stresses which may have been set up in the welding operation, and as the furnace is temperature controlled, uniformity of treatment is ensured. After slowly cooling, the joints are each checked for alignment in both the vertical and horizontal planes, the gauge shown in figure 6 being used for the purpose. The upset metal is then ground off the joint in three operations, each of which is carried out on a separate car. Figure 7 shows the machine used for grinding the metal from the top and sides of the head of the rail, and just distinguishable in the background of this illustration is a man grinding the fillet between the flange and web by means of a hand grinder driven through a flexible shaft.

The finished rails, in continuous lengths of 1 000 ft. or 1 500 ft., are pulled on to a train of flat cars drawn up to the end of the train carrying the welding equipment, a wire rope and winch, the latter mounted on one of the cars at the distant end of the train, being used for this purpose. On this train the rails can be transported either to that part of the track on which they are to be laid or to a storage yard where they can lie until required. It is a rather remarkable circumstance that the rails, which merely rest on bearers placed on the decks of the cars, as shown in figure 5, without being secured in any way, are sufficiently flexible to conform to sharp curves or even S bends in the track so that no special precautions need be taken in transporting them. Unloading the rails from flat cars for laying them, even on a curve, is a comparatively simple operation. A wire rope is attached to the end of a rail and anchored to the ground. The train of cars being then pulled away, the rail settles down on to the track, as shown in figure 8, whether the track be straight or curved, although some assistance from crowbars and chain hitches may be necessary for locating it. Generally, the rail is supported on a number of long sleepers, to which it is temporarily spiked, as shown in figure 9, being subsequently moved into the permanent way, in place of the 39-ft. rails, when traffic conditions permit. For joining long lengths of welded rail in the track to obtain continuous rails a specialised Thermit-pressure process is employed on the Delaware and Hudson Railroad, and this process is also used if it is required to replace a defective section.

To test the strength of the welded joints a large number of them have been subjected to drop tests under the standard conditions of the American Railway Engineering Association. In all these tests 6-ft. lengths of 131-lb. rail having a joint at the centre were placed on supports giving a span of 4 ft., and a 1-ton (2 000 lb.) tup was dropped on the joint from a height of 22 ft. As an example of the results obtained it may be mentioned that after two blows the deflection measured at the weld, in a particular case, was 1 1/2 in. and the elongation at the weld was 0.06 in., the rail being unbroken. In many cases, we understand, three or four blows were required to fracture the rail, and in some instances the final fracture occurred in a plane outside the weld region. The joints have also been subjected to a large number of rolling-load fatigue tests, a length of rail containing a joint being reciprocated under a wheel carrying a load of 65 000 lb. (29 tons). In these tests the welded rails have been subjected to six million passes with simple beam loading and the same number of passes with cantilever loading without showing any sign of failure. We understand that in similar tests applied to rails welded by other processes which did not include subsequent annealing failure commenced at about one million passes.

A question which arises in connection with the use of long lengths of rails and continuous rails is that of the expansion

Fig. 6. — Checking alignment of welded rail.

Fig. 7. — Grinding upset metal from rail head.

Fig. 8. — Unloading welded rails.

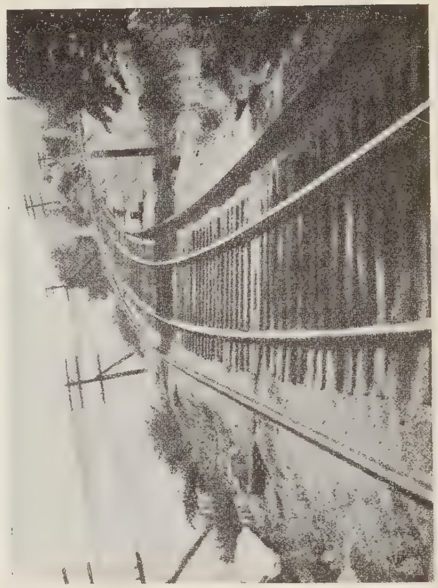

Fig. 9. — Welded rail-lengths alongside track.

and contraction due to temperature changes, and this is dealt with in an interesting paper by Mr. Alfred Africano, Jun., which appeared in the *Proceedings of the American Society of Civil Engineers* for February, 1937. Using a coefficient of expansion $\alpha = 0.0000073$ in. per degree Fahrenheit per inch of length, he shows that a stress of 21 900 lb. per square inch would be developed in a rail for a temperature change of 100° F. if the ends of the rail were fixed. The force that must be applied at each end of a 100-lb. A. R. A. rail having a cross-sectional area of 9.85 sq. in. in order to prevent expansion or contraction would therefore amount to 216 000 lb., *i. e.*, about 96 tons, and this force, it should be particularly noted, is entirely independent of the length of the rail. If a rail, 33 ft. in length, is secured to sleepers spaced on 22-in. centres there will be 18 sleepers per rail and nine at each end will have to develop between them a resistance of 216 000 lb., or an average resistance of 24 000 lb. each, to prevent end movement. Such a high resistance could only be obtained by setting the sleepers in concrete, so that actually a 33-ft. rail as ordinarily laid can contract or expand freely. The average resistance of the sleepers however, is inversely proportional to their total number, and if sixty 33-ft. lengths of rail are welded together to form a 1 980-ft. length, the average resistance per sleeper to prevent expansion or contraction would be only 400 lb., assuming the same spacing as before. In practice, however, the resistance of the sleepers is by no means uniform along the whole length of the rail, and actually, in the case of a long rail with free ends, the resistance necessary to prevent expansion or contraction is provided by only a comparatively small number of sleepers near each end. These sleepers would move by amounts diminishing towards the central portion of the rail, but those between them would show no movement; the temperature stresses in the rail thus increase more or less uniformly from zero at the free ends to a point where the maximum is reached not far from the ends and then remain constant at the maximum value throughout the whole of the central portion.

The principle is readily demonstrated by means of a simple experiment described in Mr. Africano's paper. Placing a number of slips of cardboard side by side on a flat horizontal surface to represent the sleepers, and fastening each slip to a pair of elastic cords near the ends to represent the rails, it will be obvious that if the end sleepers are pulled outwards gaps of equal width will be formed between each adjacent pair of sleepers. Then, if a separate weight be applied to each sleeper, only those near the ends will move inwards if the pull on the ends be released. There will be no diminution in the width of the gaps in the central part of the string and the elastic cords in this part will remain fully extended, even if the weights be removed from the central sleepers. The extension, of course, represents the tensile stress in the rails resulting from the contraction due to a fall in temperature, and it would be possible, though not so convenient, to repeat the experiment with compression springs between the sleepers so as to represent the condition arising from the expansion due to an increase in temperature.

That the considerations outlined above are applicable in practice is shown by some measurements made on welded rails laid in the main tracks of the Delaware and Hudson Railroad at Mechanicville, New York. It was found that the actual contraction at each end of a 475-ft. length of rail was only one half of what the free contraction would have been with the same drop in temperature, and in the case of a 2 600-ft. length the contraction was only one-eleventh of

the free contraction (*). It may be mentioned, moreover, that continuous rails 6 700 ft. in length have been in service for several years on the Delaware and Hudson Railroad with satisfactory results. In concluding his paper, the author calls attention to the fact that the principal objection to the introduction of continuous welded rail has been the fear of excessive expansion or contraction, and states that his object has been to present a theoretical explanation of the small observed expansions in existing long rails. Finally, he points out that it is only with the knowledge of what actually takes place at the ends of the rail that the proper approach can be made to the economies resulting from the elimination of rail joints.

(*) In this connection reference may be made to the remarks of Mr. A. R. Cooper, of the London Passenger Transport Board, in the discussion of the report on welded rails at the International Railway Congress, Paris, as given in *Engineering*, vol. CXLIII, page 700, (1937). See also *Bulletin of the Railway Congress*, December 1937, pp. 2219 et seq.

[625. 23 (.44)]

The « metallisation » of wooden-bodied bogie passenger coaches,

by Mr. BERTRAND,

Chef de la Division du Service Général du Matériel, French National Railways Company.

(Revue Générale des Chemins de fer.)

We will not refer again here to the advantages of replacing wooden-bodied coaches by metal stock, either from the primordial consideration of safety or as regards the cost of upkeep.

In view, however, of the increased cost of steel coaches on the one hand, and the available financial resources on the other, it will be a long time before the full programme of new constructions is completed. The new coaches, moreover, will first be earmarked to replace the four-wheeled stock still being used at peak periods in high-speed and ordinary express trains, and only later will they be available for replacing bogie stock with wooden body.

In these circumstances, the State Railways in 1937 designed and carried out the « metallisation » of one of a large class of wooden-bodied bogie coaches.

It is this work, and the collision tests that ensued, which Mr. Bertrand proposes to describe in the following note.

Objects aimed at.

Question set in 1936. — Is it possible, for a sum of less than 100 000 fr., to replace, during general overhaul, the wooden sides, ends and roof, by mass-produced metal members integrally secured to the steel underframe so as to strengthen materially the structure as a whole ?

Can this alteration be effected without dismantling the floor and internal partitions ? Can all the compartment fittings and the details for window bays, doors, heating and lighting be re-employed without alteration ?

Can all this be done *without increasing the dead weight of the coach ?*

By June, 1937, a design satisfying the above conditions had been worked out and the conversion of a specimen coach decided upon. This was completed by the end of November (see fig. 1), and in December collision tests were undertaken.

Principle of the conversion.

The interior of the coach, maintained entirely unaltered, is encased in a me-

Fig. 1.

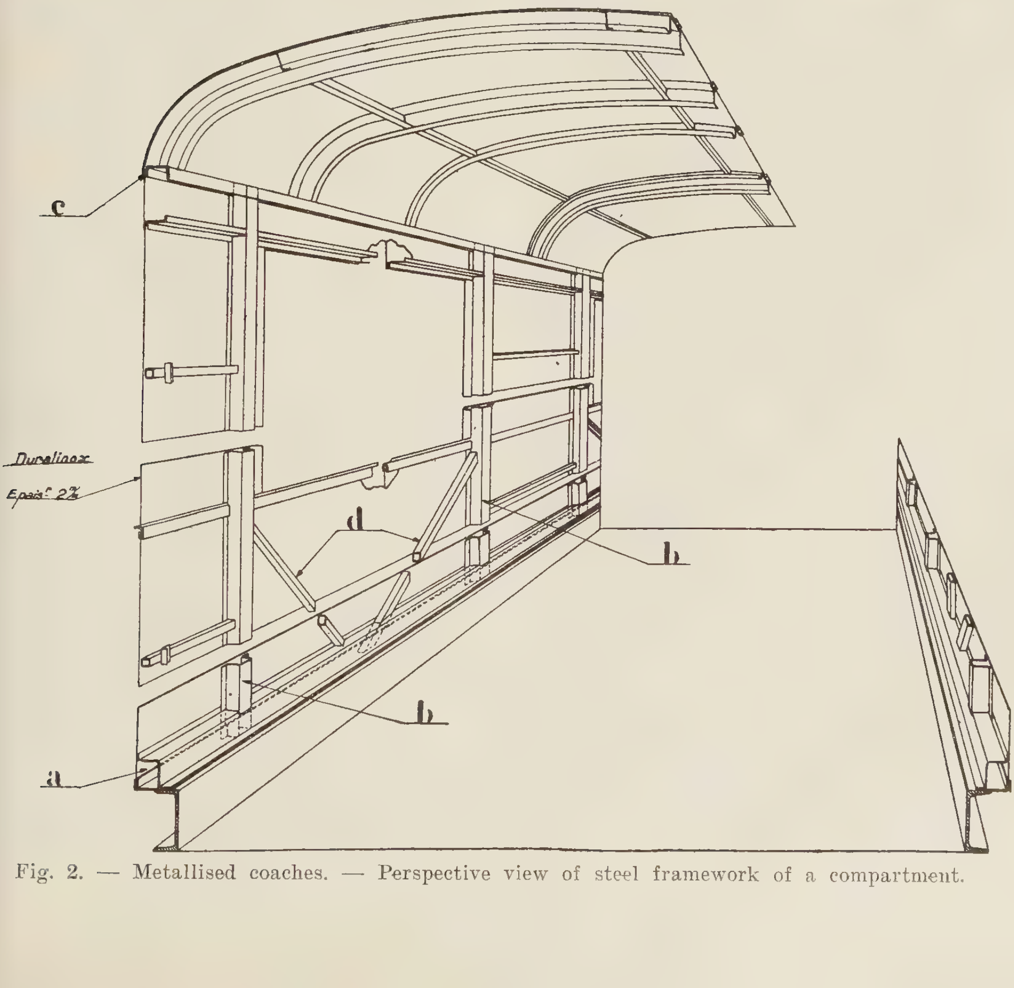

Fig. 2. — Metallised coaches. — Perspective view of steel framework of a compartment.

tal shell the members of which are formed to exact size on jigs., i.e. on mass-production lines, and economically :

The sides are rivetted to the underframe.

The roof is rivetted and welded to the sides.

The ends are of thick steel sheet, stiffened by vertical I-section shock beams the base-flanges of which are secured to a horizontal trellis girder.

The last-named is joined to the cantrails, to which both roof and sides are secured and which form two longitudinal girders connecting the two ends of the coach.

Carrying out the « metallisation ».

(a) Sides.

To make the sides solid with the solebars, they are built up on a bottom beam *(a)* into which the window pillars *(b)* are housed and welded (fig. 2).

At their top the window pillars are joined to the steel cantrail *(c)* which is thus a common member of both roof and sides. The framing is completed by pressed diagonal bracing *(d)*.

The chief component of the bottom beam (fig. 3) is a pressed steel section 2.5 mm. (0.1 in.) thick, rivetted to the solebar of the frame through a bearing plate 3 mm. (1/8 in.) thick, the outer edge of which is flanged outwards.

The side pillars are 3 mm. (1/8 in.) and 2 mm. (5/32 in.) thick, according to their position near the ends or in the middle. They are ʃ⅂ section pressings and are built-in and arc welded to the bottom beam. At the top they fit into the cantrail, which is a 2.5 mm. (0.1 in.) pressed-steel ⊓ section, the channel facing downwards. The joint between side pillars and cantrail is an arc weld, consolidated by rivets. In order to give greater rigidity to the sides, the practice has been maintained of inserting diagonal braces under the windows, the resultant triangulation keeping the pillars constantly at right angles to the solebars.

The general bracing of the sides is also ensured by two ⅂ sections, which run the whole length of the sides at window rail and waist rail height. These two members are made up of separate lengths arc-welded to the pillars.

The upper ⅂ rail together with the ⊔ cantrail form with the outer sheeting a [providing the longitudinal strength of the top of the side.

The side sheeting is of 2 mm. (5/32 in.) duralinox.

(b) Roof.

The carlines (fig. 2) are bent from 2 mm. (5/32 in.) plate, those in line with the cross partitions being of welsh hat section, and the intermediate ones in the form of ⅂ bars.

The ends of the carlines are butted and arc-welded to the web of the cantrail, in addition knees cut to the same curve act as bearing plates and are rivetted and welded to the cantrail.

The 2 mm. (5/32 in.) duralinox roof sheets are assembled edge to edge and joined to the carlines by rivetted cover strips.

The joint between roof sheeting and side sheeting is concealed under a 2 mm. (5/32 in.) strip forming a covering bead.

(c) Body ends.

The ends, being the most vulnerable elements in collisions, must be the chief object of every effort at strengthening. Reinforcement of the ends is no novelty.

Our readers will be familiar with the thick steel-sheet construction adopted for the ends of most of the French stock.

In a recent article [1] we described the method used to strengthen the ends of the light-weight steel coaches of the State Railways. Vertical beams housed in the headstock are joined at the top to a strong steel framing integral with the roof.

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(1) The new light-weight coaches of the State Railways (*Revue Générale des Chemins de fer*, issue dated 1st June, 1937).

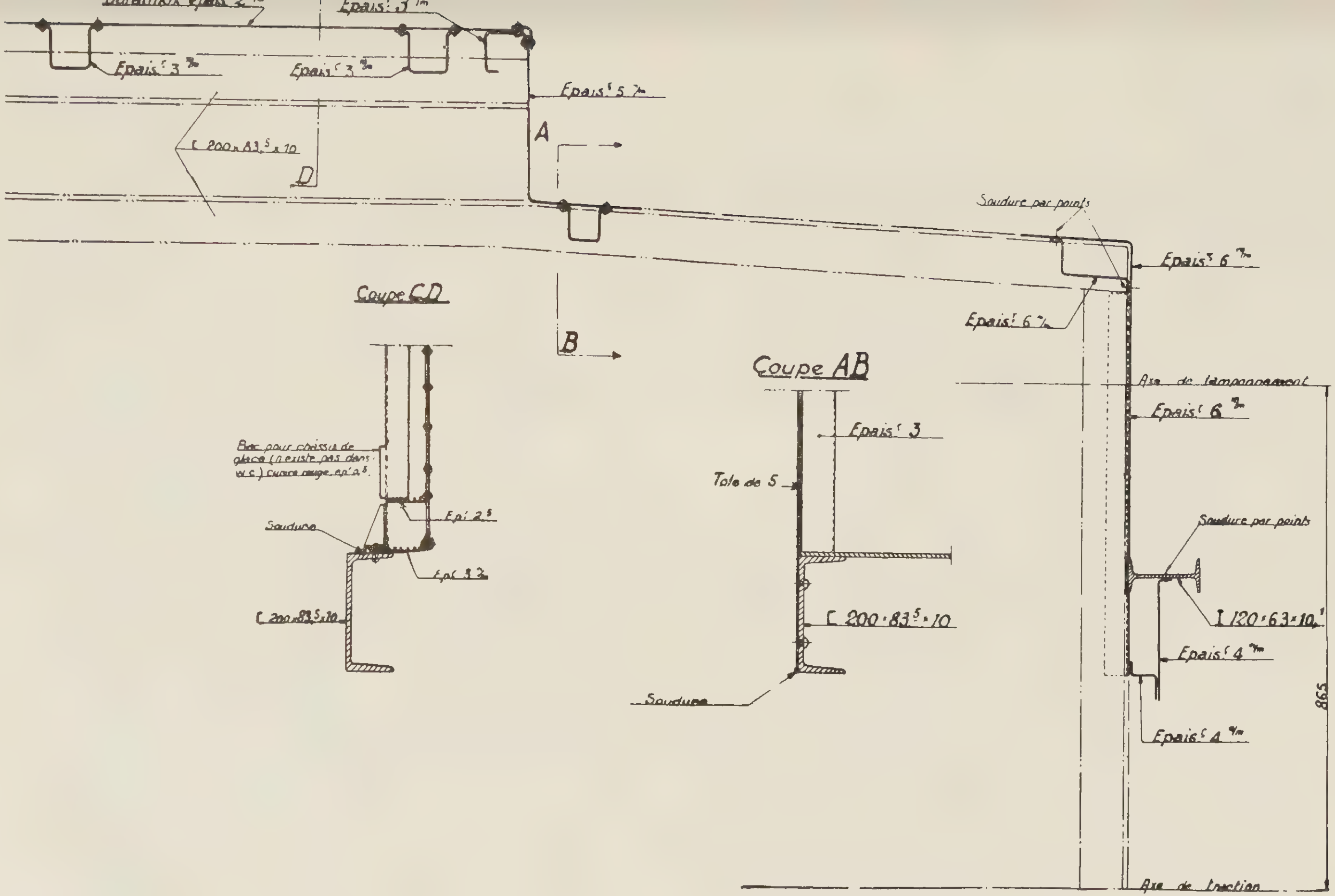

Fig. 3. — Metallised coaches. — Coach end. — Section at solebar level.

Explanation of French terms:

Axe de tamponnement = buffer centre line. — Axe de traction = centre line of coach. — Bac pour châssis... = copper light-frame tray (not fitted in lavatory). — Coupe CD (AB) = section through CD (AB). — Epaisseur = thickness. — Soudure = weld. — Soudure par points = spot weld. — Tôle = plate.

In the « metallised » coach the following arrangement was adopted.

The end proper is composed of 6 mm. (1/4 in.) steel sheeting, stiffened (figs. 4 and 4*b*) :

— on each side of the vestibule door, by a vertical I beam, (*b*), which is a component of the box pattern frame forming the vestibule door pillar (*c*).

— along the outside vertical edges by a 6 mm. (1/4 in.) steel angle (*d*), welded to the end plate to form a corner box pillar.

These active members of the end structure are carried by their base on the front of the headstock, to which they are rivetted and welded, and are connected at the top, though a horizontal trellis of square tubing (*e*) level with the cantrail, to the corner pillars of the body (*f*) and the end of the cantrail (*g*), thence through struts to the first intermediate hoop (side pillars and roof arch ribs).

The body end pillars are of 3 mm. (1/8 in.) section; they are duplicated

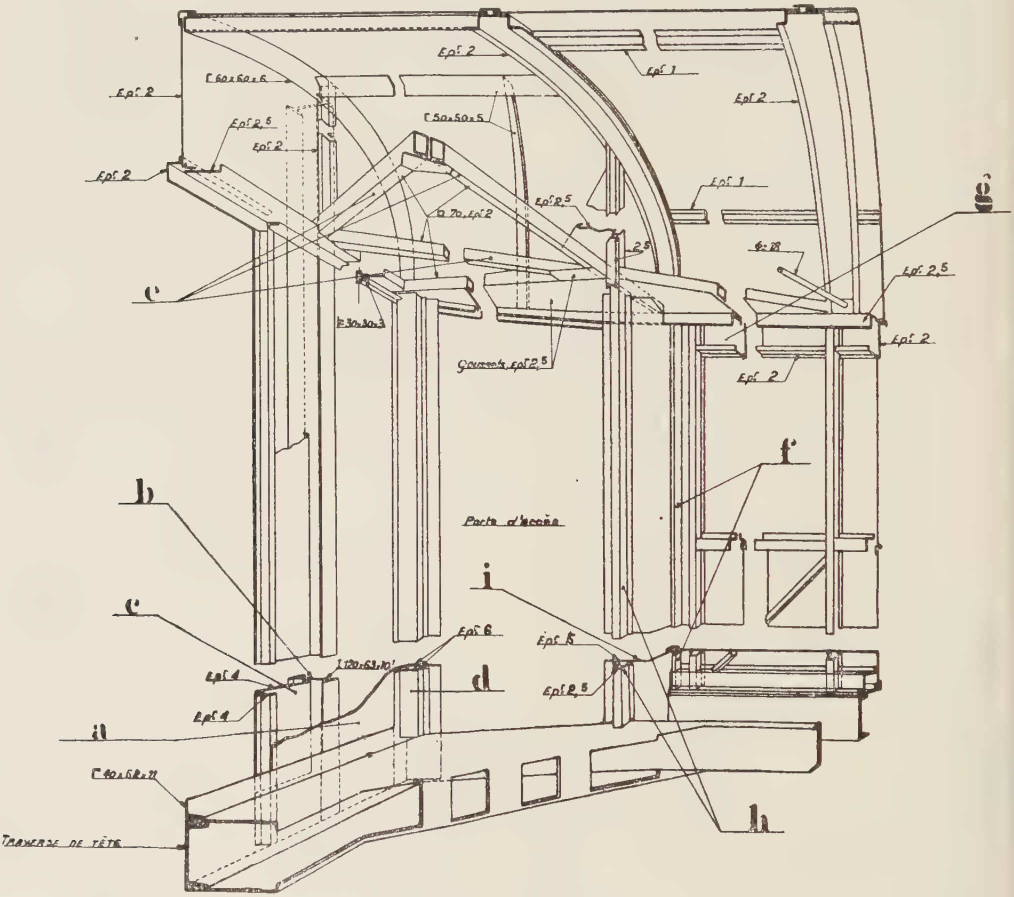

Fig. 4. — Metallised coach. — Perspective view of end framing.

Explanation of French terms:

Goussets = gusset plates. — Porte d'accès = entrance door. — Traverse de tête = headstock.

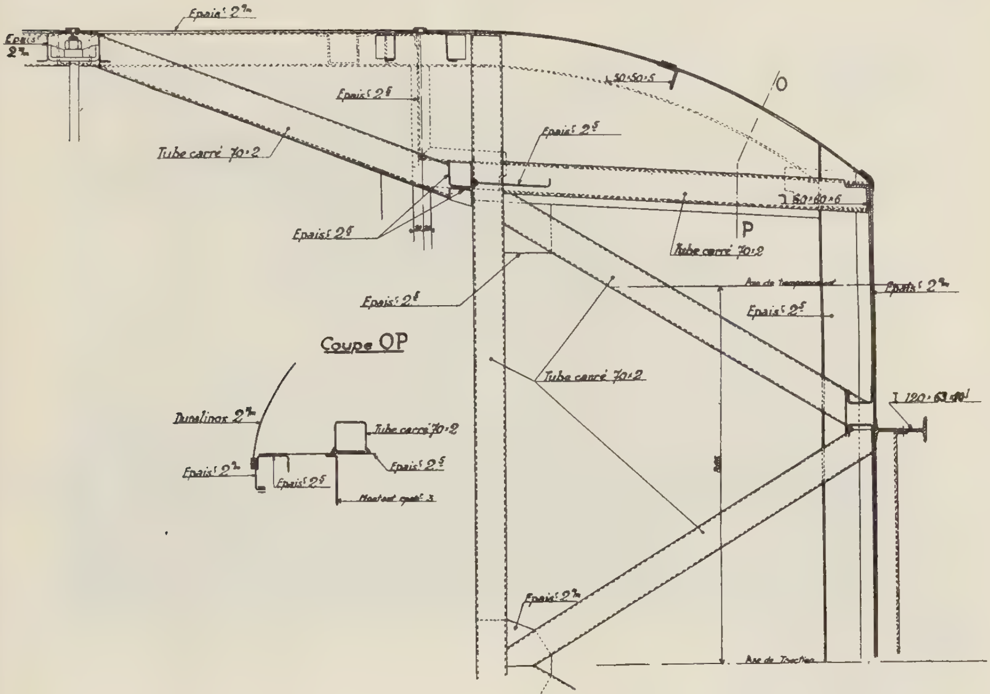

Fig. 4b. — Metallised coach. — End framing. — Section at cantrail level.

Explanation of French terms:

Axe de tamponnement = buffer centre line. — Axe de traction = centre line of coach. — Coupe OP = section through OP. — Montant = pillar. — Tube carré = square tube.

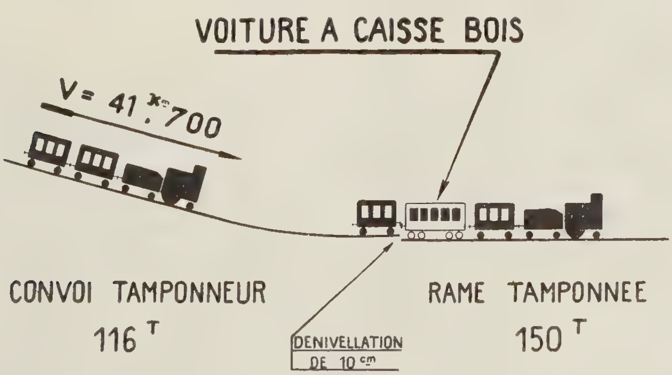

Fig. 5.

Explanation of French terms:

Convoi tamponneur 116 T. = colliding train (114 Engl. tons). — Denivellation... = difference in rail level (4 in.). — Rame tamponnée, 150 T. = stationary train. — V... = speed (25.9 miles) an hour. — Voiture à caisse bois = wooden-bodied coach.

Fig. 6.

Fig. 7.

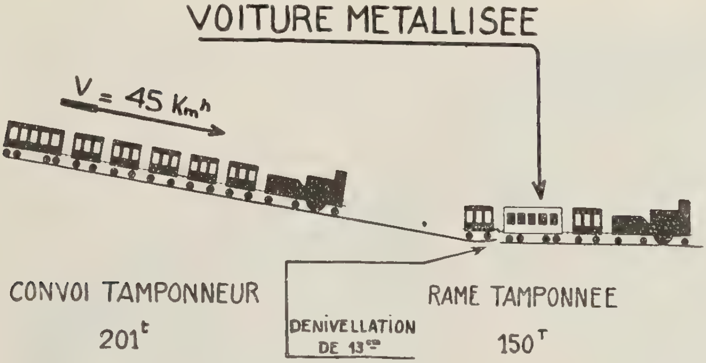

Fig. 8.

Note: V... = speed (28 miles) an hour. See also fig. 5.

by the first side pillar nearby, which frames in the lavatory light, and are connected to the side door pillars *(h)* formed of 4 mm. (1/4 in.) ⎍ sections, by a 5 mm. (13/64 in.) vertical plate *(i)* set back and rivetted to these two pillars, forming a shield parallel to the end wall.

Collision tests with the « metallised » coach.

The trial coach, reconstructed in the manner described, was subjected to tests with the object of ascertaining whether the conversion had actually made any improvement as regards ability to stand up to collisions. For this purpose, the following experiments were conducted on the Rochefort and Aigrefeuille line, which is now only used for goods traffic to and from Aigrefeuille station.

At the foot of an incline of 1 in 200 was stationed a train composed of a locomotive and tender with brakes applied, followed by the test coach between two short, but particularly strong, four-wheeled semi-steel coaches, their steel underframes being strongly reinforced by 1 m. (3 ft. 3 3/8 in.) steel plates up to the underside of the windows. In front of the locomotive a buffer stop constructed of sleepers was secured to the track, and a difference in rail level was created between the last two vehicles so as to concentrate on the end of the test coach the forces set up when this set was run into from the back, being at rest.

Fig. 9.

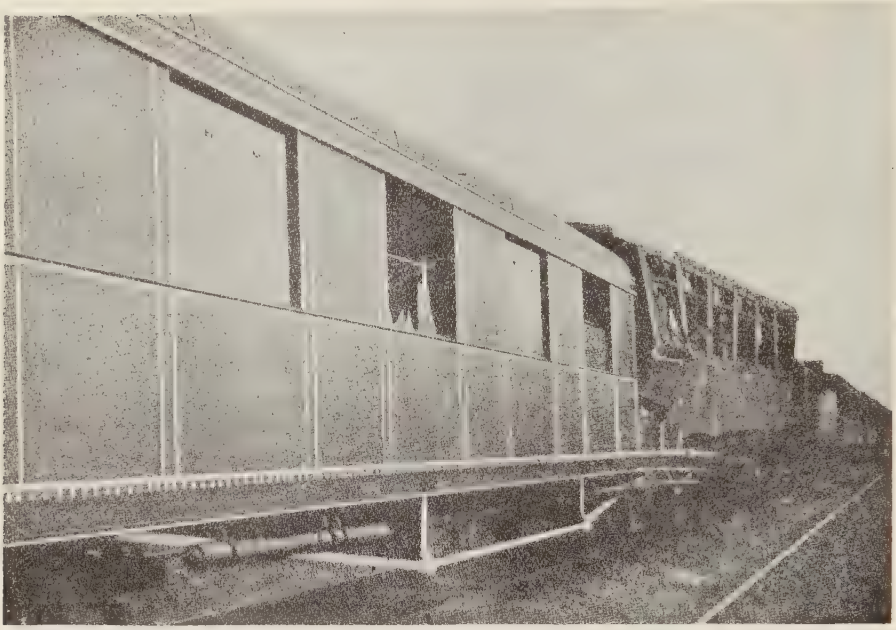

Fig. 10.

First test.

A test was first of all made with a wooden-framed bogie coach. The colliding train, consisting of a dead locomotive with tender and two vehicles, was pushed to the top of the gradient and down the incline by another engine in the rear, the latter easing off in time to stop short of the colliding point.

The difference in rail level was 10 centimetres (3 15/16 in.) (fig. 5).

In this first test the rear vehicle of the stationary train was driven right through the wooden-framed bogie coach, the semi-steel coach being relatively only slightly damaged in the process (fig. 6).

Second test.

The wooden-framed coach was then replaced by the « metallised » coach, which completely resisted the impact (fig. 7), the speed of the colliding train being 41.7 km. (25.9 miles) an hour, recorded electrically. The rear coach was burst open at both ends and forced right round the end of the metallised coach. When the latter vehicle was drawn clear, it was found that even the end window panes were undamaged with the exception of one door light through which a piece of timber from the other coach had been driven. No distortion of either ends, side walls or roof could be discovered.

When the « metallised » coach was weighed after the conversion it was found that not only had the original tare not been exceeded but a reduction of 500 kgr. (1 100 lb.) had actually been effected, and the question arose as to the point where that weight of metal could be added to best advantage. For this purpose, a second series of collision tests was carried out.

The weight and speed of the colliding train were augmented, the latter from 41.7 km. (25.9 miles) to 45 km. (28 miles) an hour, and the difference in rail level was increased to 13 cm. (5 1/8 in.)

which, allowing for the overhang, gave a maximum difference in buffer level of 18 cm. (7 3/32 in.) (fig. 8).

Third test.

The test under the revised conditions was first carried out with a wooden-bodied bogie coach; the semi-steel coach completely cut off the wooden body of the tested coach (fig. 9), as also the back of the coach in front of the bogie coach.

Fourth test.

The wooden coach was then replaced by the « metallised » coach other conditions remaining equal. The manner in which the end, roof and sides stood up to the impact can be seen from the photograph (fig. 10).

No strengthening of sides or roof having been found necessary, it was decided to strengthen *the end,* as already explained, by using 6 mm. (1/4 in.) steel end plates and I sections with reinforced web made of PM 20 steel, having an elastic limit of 48 kgr./mm^2 (30.5 tons per sq. in.) instead of 20 kgr./mm^2 (12.7 tons) as previously, so as to prevent permanent set in the event of impacts sufficient to fracture the ordinary steel I sections.

[621. 13 (.42) & 669 (·42)]

The metallurgy of a high-speed locomotive (*).

A survey of the materials used in the construction of the streamlined express engines of the L. M. S. R., with details of analyses and tests.

In *The Railway Gazette* of May 28, 1937, we published an article illustrating and describing the first of the 4-6-2 streamlined express locomotives of the London Midland & Scottish Railway, No. 6220, *Coronation.* Five engines, known officially as the « Princess Coronation » class, were built in 1937 at the company's works at Crewe in accordance with this design, the others of which were numbered and named, 6221, *Queen Elizabeth;* 6222, *Queen Mary;* 6223, *Princess Alice;* and 6224, *Princess Alexandra.* As was then stated, the new locomotives represent a development of the earlier 4-6-2 engines of the *Princess Royal* type, but in addition to being provided with streamlining, the boiler is of considerably greater capacity, while certain improvements have been made to the frames and valve motion.

The form of streamlining adopted was finally decided after very careful experiments with models in the L. M. S. R. Research Department's wind tunnel at Derby, where tests were carried out to represent both head winds and winds crossing the tracks at various angles.

The following are the principal particulars :

Cylinders (4), diam. × stroke	16 1/2 in. × 28 in.
Valve gear	Walschaerts (2 sets).
Valve travel	7 1/32 in.
Coupled wheels, diam.	6 ft. 9 in.
Boiler :	
Working pressure	250 lb. per sq. in.
Firebox heating surface	230 sq. ft.
Tube heating surface.	2 577 »
Total (evaporative)	2 807 »
Superheater	856 »
Combined heating surface	3 663 »
Grate area.	50 »
Tractive effort at 85 per cent. boiler pressure	40 000 lb.

These locomotives were specially con-

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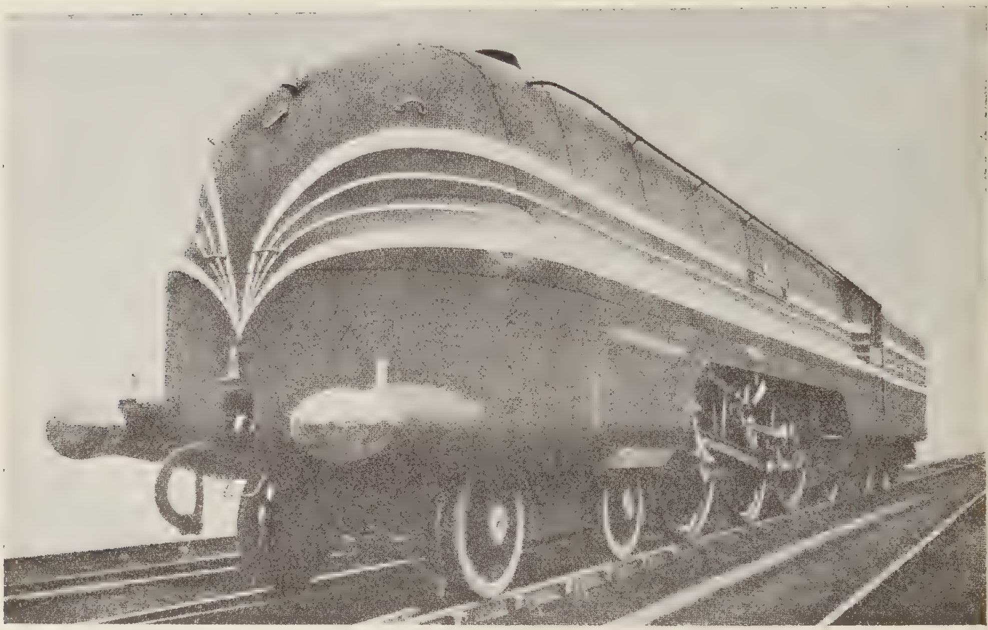

Fig. 1. — Streamlined 4-6-2 type express locomotive « Princess Coronation » class, L.M.S.R.

structed for working the L. M. S. R. accelerated 6 1/2-hour express services between Euston and Glasgow, with one stop, at Carlisle, in each direction. The distance is 401 1/2 miles, giving an average speed, allowing for the stop at Carlisle, of 62.6 m.p.h. The engines have proved highly successful, and the percentage of punctual arrivals at each end has been uniformly high.

In view of the interest attaching to the locomotives, and the work they do, we formed the opinion that among the Readers of *The Railway Gazette* both at home and abroad, there would be very many whose interest is not merely centred in the design and performance data of the type, but who would like to have information bearing upon the metallurgical side of the subject. This is a very important aspect of locomotive design, especially where engines are built to work at unusually high speeds for relatively long periods at a time, and under conditions in which complete reliability plays such an important part.

The *Coronation* locomotive, although ranking as the first streamlined express engine on the L. M. S. R., and being specially intended for high-speed service, is not actually one in which any very great departure has been made from current practice, so far as the materials of which it is constructed are concerned. In instituting so important a service as that of the Coronation Scot train, the first and essential requisite of the locomotive was that already referred to — namely, complete reliability. For this reason previously untried and experimental materials were not used, and no material has been built into the engine which has not already been incorporated in some form or other on modern locomotives of the L. M. S. R. From the

purely metallurgical point of view, therefore, the engine may be said to embody all that is of true worth in the best modern practice. On the other hand, the design of so powerful an engine within the allowable axle weights was not accomplished without very particular thought being given to the metallurgical side, even within the limitations above outlined; and by the courtesy of the company's Chief Mechanical Engineer, Mr. W. A. Stanier, we have been given access to sources of information and data regarding the problems that arose, and the means adopted to meet them.

The basis of the *Coronation* design was the already successful *Princess Royal* class of engine, the first of which was built at the L. M. S. R. Crewe works in 1933, and of which illustrated particulars were given in the issue of *The Railway Gazette* dated June 30, 1933. To meet the projected services embodying the high-speed runs between Euston and Glasgow, certain alterations were considered necessary, these consisting mainly of increased boiler capacity, larger coupled wheels, and the introduction of streamlining. The latter, on the ground that it would prevent ready access between the frames, suggested the elimination of the separate inside valve gears. A slight increase in cylinder diameter was called for, to maintain the same tractive effort with the larger coupled wheels, but at the same time the weight on these wheels — 67 tons 10 cwt. — could not be exceeded.

Boiler design and materials.

The boiler of the locomotive has a length of 19 ft. 3 in. between tubeplates, and is tapered from a diameter of 6 ft. 5 1/2 in. at the firebox end to 5 ft. 8 5/8 in. at the smokebox (both outside dimensions). It contains 129 small tubes 2 3/8 in. diam., and 40 flue tubes, the latter containing triple superheater elements 1 in. outside diameter, so that the steam passing to the cylinders is split up into 120 paths. The boiler shell is constructed of 2 per cent. nickel steel, and the inner firebox, which is of copper, is extended into the barrel to form a combustion chamber.

The physical properties and analysis called for in the material used for the boiler and outer firebox shell, are as follow :

Analysis :	Per cent.
Carbon	0.2-0.25
Silicon	0.1-0.15
Manganese	0.5-0.7
Sulphur	0.04 max.
Phosphorus. . . .	0.04 »
Nickel	1.75-2.0
Physical properties :	
Maximum stress . .	34-38 tons per sq. in.
Yield point. . . .	17-19 » »
Elongation	22-24 per cent. on 8 in. gauge length.
Reduction in area .	50 per cent. min.
Ratio of yield point to maximum stress	50 » »

Table I having reference to steel for boiler plates and staybolts and Monel metal stays, gives some actual representative figures for these materials obtained on test. The degree of relationship between the specified and actual figures can be noted therefrom under each of the different headings. This applies equally to Tables II and III, referring to other portions of the construction.

The normal carbon steel used for locomotive boiler plates has a tensile strength of 26-30 tons per sq. in. with an elongation of not less than 22 per cent. on a gauge length of 8 in. The increased tensile strength of the nickel steel has allowed the reductions in thickness and savings in weight shown in the small table under Table I, page 138, to be made on the *Coronation* boiler as compared with what would have been the case had carbon steel been used.

From the figures therein, it will noted that a saving of over two tons was

Material.	Maker.	Cast No.	Breaking stress, tons per sq. in.	Elongation, % on 8 in.	Ratio, y.p./m.s. %	C o
Acid nickel steel boiler plate.	Colvilles Limited.	B. 7364	36.3	25.0	62.8	
		»	36.8	23.0	60.8	
		D. 7305	35.7	23.0	66.1	
		»	35.4	23.5	66.9	
		C. 6960	34.8	24.0	59.6	
		»	34.2	24.0	59.0	
		D. 7189	35.8	26.0	63.9	
		»	35.7	24.5	64.7	
		C. 6692	34.9	26.0	55.9	
		»	34.8	27.0	56.8	
		Y. 6932	35.8	23.0	59.4	
		»	34.5	22.0	59.2	
Specified			*34/38*	*24/22*	*50 min.*	5
Acid steel bars for boiler stays (Transverse & longitudinal).	Colvilles Limited.	A. 6653	41.9	20.0	63.4	
		»	41.9	22.0	64.4	
Specified			*37/43*	*18 min.*		
				On 2 in.	Yield stress, tons per sq. in.	
Hot rolled Monel metal.	Henry Wiggin & Co. Ltd.	3153	34.8	52.0	16.0	
		2999	36.4	52.0	14.8	
Specified			*30/35*	*35.0*	*14/17*	

For reference to the above table see also page 142.

—	Nickel steel boiler as built. Thickness of plates.	Boiler if made of mild steel. Thickness of plates.	Increase in weight of mild steel boiler over nickel steel.			
	In.	In.	T.	Cwt.	Q.	Lb.
First barrel	5/8	13/16	...	12	0	6
Inside cover strap. . .	9/16	3/4	...	1	0	1
Outside » . . .	9/16	3/4	...	...	1	25
Liner for top feed seating	9/16	11/16	...	...	1	3
Second barrel	11/16	7/8	...	14	0	0
Inside cover strap. . .	9/16	3/4	...	1	0	9
Outside » . . .	9/16	3/4	...	...	2	2
Liner for dome seating .	13/16	1	...	...	2	13
Throat plate, top half .	3/4	7/8	...	...	2	17
Throat plate, bottom half	3/4	7/8	...	2	1	20
Firebox backplate . . .	9/16	5/8	...	1	0	24
Steel wrapper	1/2	5/8	...	9	0	3
			2	3	1	11

Bend test.	Chemical analysis. C %	Si %	Mn %	S %	P %	Ni %	Cu %	Cr %	Mo %
parallel 1 7/8 in. rt without frac- e.	0.22	0.12	0.64	0.030	0.032	1.96			
Do. 1 3/4 in.									
Do. 7/8 in.	0.215	0.13	0.65	0.033	0.030	1.83			
Do. 3/4 in.									
Do. 1 1/4 in.	0.25	0.15	0.69	0.034	0.026	1.84			
Do. 1 1/8 in.									
Do. 7/8 in.	0.22	0.13	0.66	0.030	0.030	1.83			
Do. 3/4 in.									
Do. 1 1/4 in.	0.245	0.18	0.62	0.024	0.029	1.85			
Do. 1 3/8 in.									
Do. 1 1/4 in.	0.23	0.13	0.59	0.029	0.031	1.80			
Do. 1 1/8 in.									
	0.2/0.25	*0.1/015*	*0.5/0.7*	*max. 0.040*	*max. 0.040*	*1.75/2.00*			
sides parallel, 1 in. rt without frac- e.	0.265	0.10	1.70	0.031	0.040				
without fracture.	*0.22/0.28*								

	Ni %	Cu %	Mn %	Fe %	Si %	S %	C %	Brinell hardness No.
	68.41	28.83	1.03	1.55	0.05	0.010	0.10	121
	66.58	31.13	0.96	1.11	0.05	0.005	0.14	126
								110/120

obtained in the construction of the boiler shell and firebox by the use of the nickel steel, the empty weight of the boiler, including mountings, being 28 tons 3 cwt. 2 qr. This represents a most valuable gain, as it permits of a boiler being used of the maximum diameter which can be mounted between the coupled wheels and within the loading gauge, and it is to be noted that the boiler centre is placed 9 ft. 6 in. above rail level. No diversion from normal practice was necessary in bending the nickel steel barrel and wrapper plates; the cutting procedure, however, required some modification. Whereas for ordinary mild steel plates, oxy-acetylene is used, and the plate cut with only a small chipping allowance, coal gas was used for the nickel steel plates, as this gives a less severe chill effect and prevents consequent cracking. An additional chipping margin was allowed against such chilling effects as were present. Annealing treatment was carried out on the throat plates to relieve the stresses caused by local heating during manufacture, but, we are informed, it may be possible to eliminate this procedure in future, by using a special setting block, so that the complete bending operation may be carried out with a general heat on the whole plate. Annealing was also required for the butt straps, for the reason that in the untreated condition, the chilling which occurs after the flame

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Material.	Maker.	Cast No.	Breaking stress, tons per sq. in.	Elonga-tion, %	Yield point, tons per sq. in.	Contr'n. of area, %	Bend
High tensile acid steel frame plate grade « B ».	Colvilles Limited.	C. 6689	37.0	23.0	23.9	53.1	Sides p 1 3/8 in. without
		»	37.2	24.0	23.8	55.8	Do. 1
		B. 7369	36.1	25.0	22.0	54.0	Do. 1
		»	35.4	22.0	22.2	42.8	Do. 1
		B. 7362	36.0	23.5	22.1	50.1	Do. 1
		»	36.8	24.0	24.1	47.5	Do. 1
		D. 7350	38.1	23.0	22.2	51.8	Do. 1
		»	37.9	22.0	22.1	51.2	Do. 1
		D. 7349	38.4	24.0	22.3	50.6	Do. 1
		»	39.1	23.0	23.1	48.2	Do. 1
		»	39.9	23.0	23.8	47.6	Do. 1
Specified.			*35/40*	*20 min.*	*22 min.*	*40 min.*	
Vibrac steel coupling and connecting rods.	The English Steel Corporation Limit- (Vickers Works).	P. 7151/4	56.0	On 2 in. 25.0		63.6	18
		16168/3	57.3	23.0		59.2	180°
		P. 6859/32	55.0	22.5		60.4	»
		3049/1	56.8	21.5		57.0	»
Specified.			*50/60*				

T

Material.	Maker.	Cast No.	Breaking strength, tons per sq. in.	Elongation, %	Ratio yp./bs., %	Contr'n. of area, %	Cold bend test. 1 1/4 in. sq.	Chemical analy			
								C %	Si %	Mn %	S %
Acid steel loco. axles (*).	Steel, Peech & Tozer.	19/9815	37.58	On 3 in. 28.3	61.2	54.20		0.26	0.211	0.85	0.033
		"	37.05	30.6	61.2	55.88	180° E.T.W.F.				
Specified			*35/40*	*25/20*			*180° E.T.W.F.*				*0.040 max.*
Acid steel loco. tyres 3 ft. 2 3/4 in. i/d. pony truck (†).	English Steel Corporation Ltd.	P. 6726	60.5	On 2 in. 15.5		24.6		0.61	0.81	0.56	0.030
Specified : L.M.S.R. 8D. class « DC ».			*56/62*	*13/11*							*0.040 max.*
Acid steel loco. tyres 6 ft. 2 3/4 in. i/d.	Steel Co. of Scotland Ltd.	U. 450	53.37	21.0		33.4		0.52	0.298	0.72	0.031
Specified : L.M.S.R. 8D. class « CB ».			*50/55*	*18/15*							*0.040 max*

(*) Axles were subjected to a falling weight test in the following conditions : Weight of 2 240 lb., fallin
straight; 3 3/16 in.; straight; and 3 5/16 in.; all without fracture.

(†) « As rolled » co

For reference to th

					Chemical analysis.				Izod impact test			Heat treatment.
									Ft.-lb.			
	Si %	Mn %	S %	P %	Ni %	Cu %	Cr %	Mo %	1	2	3	
	0.13	0.90	0.031	0.032		0.32	0.365					
	0.10	0.90	0.031	0.027		0.36	0.42					
	0.10	0.91	0.031	0.029		0.35	0.39					
	0.11	0.97	0.032	0.035		0.35	0.39					
	0.10	1.03	0.034	0.034		0.38	0.32					
5	*0.10/0.20*	*0.85/1.0*	*0.040*	*0.040*		*0.30/0.50*	*0.45*					
	0.22	0.60	0.029	0.028	2.45		0.66	0.59	50	42	40	Hardened : 850° C., oil quenched. Tempered : 650—670° C. air.
	0.22	0.57	0.031	0.032	2.53		0.58	0.63	55	54	49	Do.
	0.26	0.63	0.027	0.028	2.62		0.68	0.60	65	63	62	Do.
	0.21	0.57	0.038	0.029	2.58		0.56	0.55	44	47	47	Do.

Izod impact test			Heat treatment.	Spec'd. deflection.	Total deflection, in inches, produced by a weight of 2 240 lb. falling successively from heights of :—									
1 Ft.-lb.	2 Ft.-lb.	3 Ft.-lb.			10 ft.	15 ft.	20 ft.	25 ft.	30 ft.	30 ft.	30 ft.	30 ft.	30 ft.	30 ft.
			Reheated to 860° C. and oil quenched for 4 minutes.	Without fracture.										
3.0	6.0	4.0		2.2	1/4	3/4	1 3/8	2 1/4	3 1/8	3 3/4	Without fracture.			
4.0	4.0	3.0	Reheated to 830° C., quenched in oil, tempered 650° C.	10 3/4	1/4	3/4	1 5/8	2 3/4	4 1/16	5 1/8	6 3/16	7 3/16	8 3/8	9 9/16"
					30 ft. 10 7/16	20 ft. 10 3/4	30 ft. 11 7/16	30 ft. 12 1/4	Without fracture.					
					The total deflection to be not less than the specified deflection.									

.am. at centre 6 3/8 in., and distance between supports 5 ft. Deflections under 5 blows were 3 1/2 in.;
›resents bogie tyres (same cast).

.e pages 148 to 152.

cutting is detrimental to the life of the planing tools.

It is the standard practice on the L. M. S. R., in boilers pressed to 250 lb. per sq. in., for certain portions of the longitudinal barrel seams of the steel wrapper plates to be welded. In the case of nickel steel, certain precautions are essential in the welding, to obviate hardness in the heat-affected zone of the parent plate adjacent to the weld; this is overcome by the use of specified electrodes, and a technique which ensures that sufficient heat is generated due to comparatively slow manipulation of the rod, thus obviating a severe quenching action. In addition, the pads for boiler mountings and various snubs and handrail pillar brackets are dealt with in like manner.

The inner firebox is of copper, and it is specified that the plates shall contain not less than 99.2 per cent, of copper; not less than 0.30 per cent. nor more than 0.50 per cent. of arsenic; not more than 0.05 per cent. of antimony nor more than 0.01 per cent. of bismuth. The tensile strength called for is a minimum of 14 tons per sq. in. with an elongation of not less than 35 per cent. measured on a length of 8 in. The firebox staybolts are of steel, except for those portions of the firebox sides subject to the greatest relative movement due to expansion, in which case they are of Monel metal. The steel stays, which are 1/2 in. diameter in the turned-down centre portion, are made from acid steel bar for which a tensile strength of 32-37 tons per sq. in. is called for, with a minimum elongation of 23 per cent. on 2 in. gauge length. The carbon is from 0.12 to 0.18 per cent. The Monel metal stays have a diameter of 5/8 in. in the turned-down portion. This material has a high ductility similar to copper, but combined with a higher tensile strength, which enables a smaller diameter stay to be used for a given strength, and this in consequence, increases the ratio of length to diameter of the stay, making for greater flexibility. This feature is particularly advantageous for the reason, as is well known, that the majority of firebox stay failures are due more to fatigue than to excessive stress. The breaking strength of the Monel metal bar used for making the stays is specified as 30-35 tons per sq. in., with an elongation of 35 per cent. on a 2 in. gauge length. The Brinell hardness of the material is 110/120.

It is customary for Monel metal to be supplied to a chemical analysis as follows :

Nickel, not less than 64 per cent, nor more than 70 per cent.

Manganese, not less than 0.3 per cent, nor more than 2.0 per cent.

Iron, not more than 2.5 per cent.

Total impurities, not more than 0.3 per cent.

Copper, the remainder.

The figures appearing in Table I under the heading of « Chemical Analysis », should therefore be read as applicable to the case of the L. M. S. R. locomotives which form the subject of this article.

While on the subject of the boiler, it will be of interest to refer to the material used for the smokebox, smokebox door, and ashpan, parts of which are subject to the corrosive action of hot ashes. These parts are made of copper-bearing steel, the specification calling for a steel having 0.30 to 0.35 per cent. of copper, and not more than 0.06 per cent. of sulphur or phosphorus. The tensile strength of this material is 28-32 tons per sq. in., and no difficulty is experienced in fabricating it by welding, as in the case of the ashpan. The use of this steel is based on the findings of the Research Committee of the Iron and Steel Institute, which have indicated its increased resistance to corrosion, as compared with mild steel.

The engine main frames.

The main frames of the engine (figs. 13 and 14) are made of a special high tensile acid steel, and are 1 1/8 in. thick. At each side at the hind end, two separate frame plates are spliced to the main frames, and carried through to the hind buffer beam. The outer frames are splayed outwards, and the inner frames inwards, to take the side bearers for the trailing two-wheeled truck.

The required specification entailed a considerable amount of investigation, which was carried out by the railway company on various special steels, particularly from the point of view of welding and cutting by oxy-coal gas and oxy-acetylene. From the results obtained, a specification was drawn up limiting and controlling the carbon, manganese, and chromium contents, and to ensure that the heat and quenching effect of a cut edge, or in the zone adjacent to a weld, should not give rise to excessive hardness. The analysis and physical properties of the steels used on the frames are as follow :

Analysis :	Per cent.
Carbon	0.20-0.25
Silicon	0.10-0.20
Manganese	0.85-1.0
Sulphur	0.04 max.
Phosphorus	0.04 max.
Chromium	0.45 max.
Copper	0.30-0.50
Physical properties :	
Maximum stress	35-40 t. per sq. in.
Yield point	22 t. per sq. in. min.
Elongation	20 per cent. min.
Reduction in area	40 per cent. min.

Figures taken from the actual tests made on this material are as follow :

Physical tests.

Cast.	Breaking stress, tons per sq. in.	Elongation, per cent.	Ratio yield to maximum stress, per cent.	Contraction of area, per cent.
A	36.1	25.0	22.0	54.0
	35.4	22.0	22.2	42.8
B	36.0	23.5	22.1	50.1
	36.8	24.0	24.1	47.5

Chemical Analysis.

Cast.	C	Si	Mn	S	P	Cu	Cr
A	0.245	0.10	0.90	0.031	0.027	0.36	0.42
B	0.23	0.10	0.91	0.031	0.029	0.35	0.39

Although steps were taken in the specified analysis to obviate hardness on gas-cut edges, certain precautionary measures were found advisable, such as cutting speeds slower than the normal; or, alternatively, subsequent tempering after the cutting of the edge by blowpipe. During the welding of such steels, pre-heating was resorted to where possible, but where not practicable, the deposition of weld metal was done slowly with a view to reducing severe quenching action. The higher tensile strength of this material allows the frames to be made of 1 1/8-in. plates instead of the 1 1/4-in. which would be necessary with ordinary carbon steel. The total

weight saved on a pair of frames by this means is 17 cwt.

Cylinders and motion.

In this locomotive there are, as previously stated, four cylinders 16 1/2 in. diam. × 28 in. stroke. Steam is distributed by piston valves of 9 in. diameter, having a maximum travel of 7 1/32 in. These valves are actuated by two sets of Walschaerts gear situated outside the frames, which drive the outside piston valves direct, and the inside ones by means of rocking levers; the whole arrangement is specially designed to allow the removal of both sets of valves for examination with the minimum amount of trouble. The valve motion is provided with Hoffman needle bearings, except the return crank ends of the eccentric rods, which are fitted with SKF self-aligning ball bearings.

The inside cylinders drive the crank axle of the leading coupled wheels, whilst the connecting rods of the outside cylinders drive on the crank-pins of the second pair of coupled wheels direct.

The mixture used in the manufacture of the cylinders was comprised of 50 per cent. cylinder scrap and 50 per cent. special low phosphoric pig iron. The analysis of a typical cylinder mixture is as follows :

Carbon	3-3.3	per cent.
Silicon	1.2-3	»
Manganese.	0.8-0.9	»
Sulphur.	0.1	» max.
Phosphorus	0.5	» »

The cupola melting of this metal was carefully controlled, and the tapping and casting temperatures carefully watched by means of a Cambridge disappearing filament pyrometer. The cylinders were cast at a minimum temperature of 1 250° C. The metal for the piston valve liners, piston heads, and piston rings, is of similar material, and the same method of control was adopted for these details. In addition to the cylinder castings themselves, test bars were also cast; these were of the L. M. S. R. standard rectangular specimen for transverse breaking load, approximately 3 ft. 6 in. long by 2 in. by 1 in., the centres for breaking being taken at 36 in. The specification for these bars is : breaking stress minimum 30 cwt., with minimum 1/2 in. deflection. From the bar a hardness survey is made of the cross section, the Brinell numbers generally being in the neighbourhood of 220-230. Test bars are also cast integrally with the cylinder for tensile and transverse tests, the transverse centres in this case being 12 in. The maximum stress obtained is in the region of 15-16 tons per sq. in.

Although more closely connected with the reciprocating parts to be discussed later, it is convenient to refer to the piston valves, the material being the same as in the case of the cylinders. Here, however, the design has been modified to allow a lighter web than usual to be used. This valve is illustrated (fig. 5), and the total weight saved for the four sets of valves is 96 lb. over the standard design. The weight of the four piston valves complete with spindles is 4 cwt. 2 qr.

Weight reduction and balancing.

In the *Coronation* engine, 50 per cent. of the reciprocating weights are balanced, equally divided over the three coupled axles (see fig. 2). In a four-cylinder engine, it is possible to eliminate axle hammer blow altogether, so long as the same amount of reciprocating weight is balanced in both the inside and outside motions. There remains, however, a small hammer blow on each wheel, and it is therefore desirable to reduce the value of the weight as far as possible. In the *Princess Royal* class locomotives, the hammer blow on each coupled wheel is 1.31 tons. For

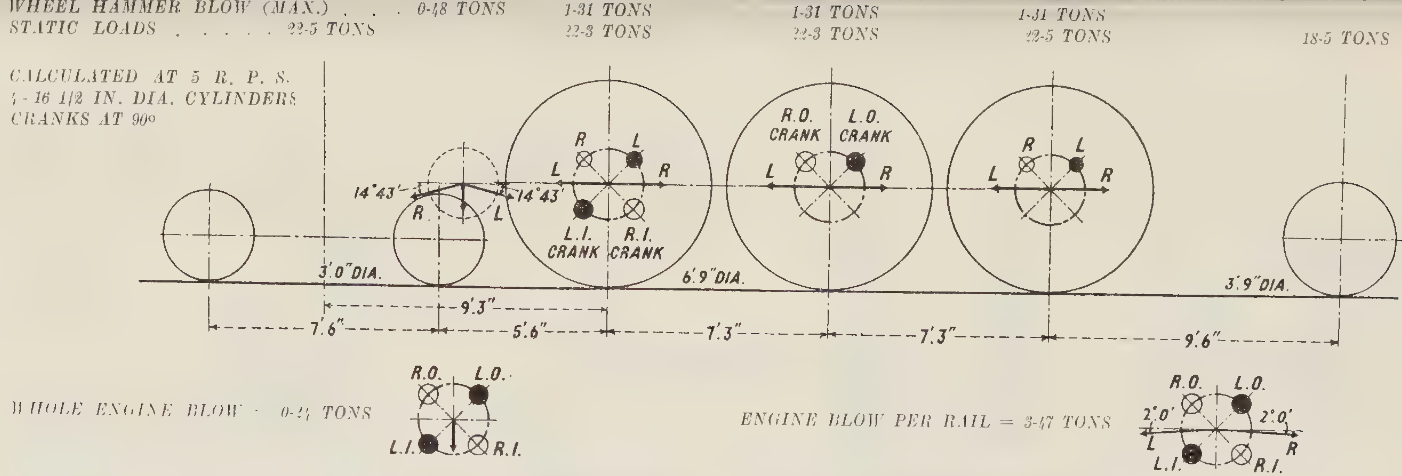


Fig. 2. Wheel balancing diagram. Four cylinder 4-6-2 type locomotive.

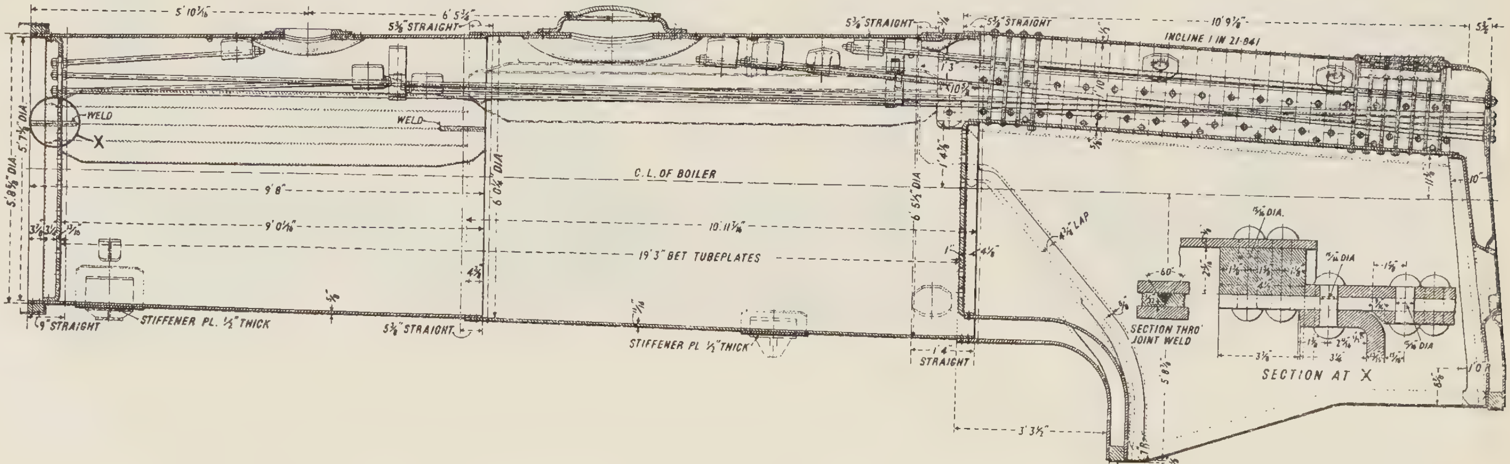


Fig. 3. — Sectional elevation of boiler, with details of welded and riveted joints.

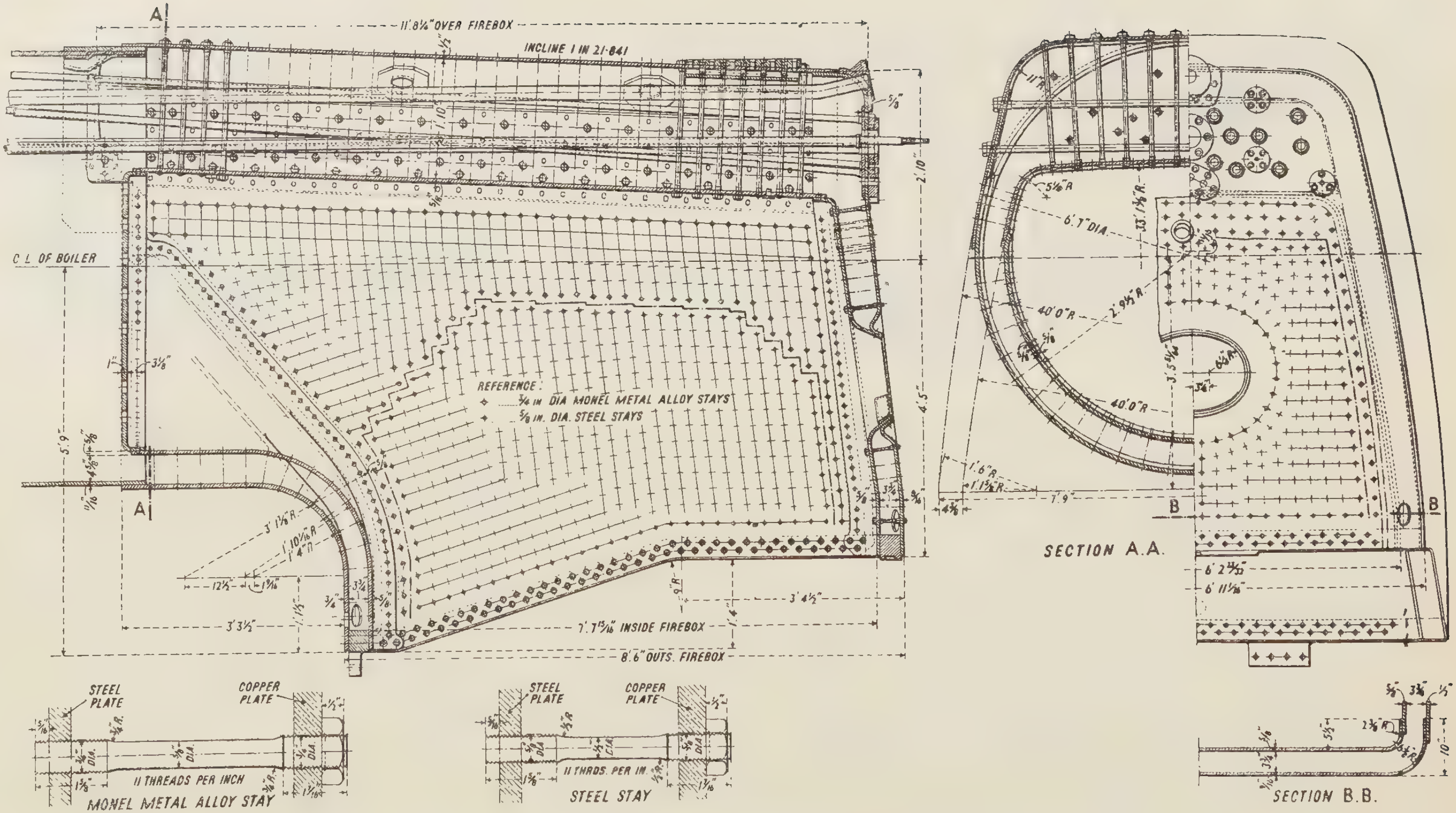


Fig. 4. — Longitudinal and cross sections through firebox and combustion chamber.

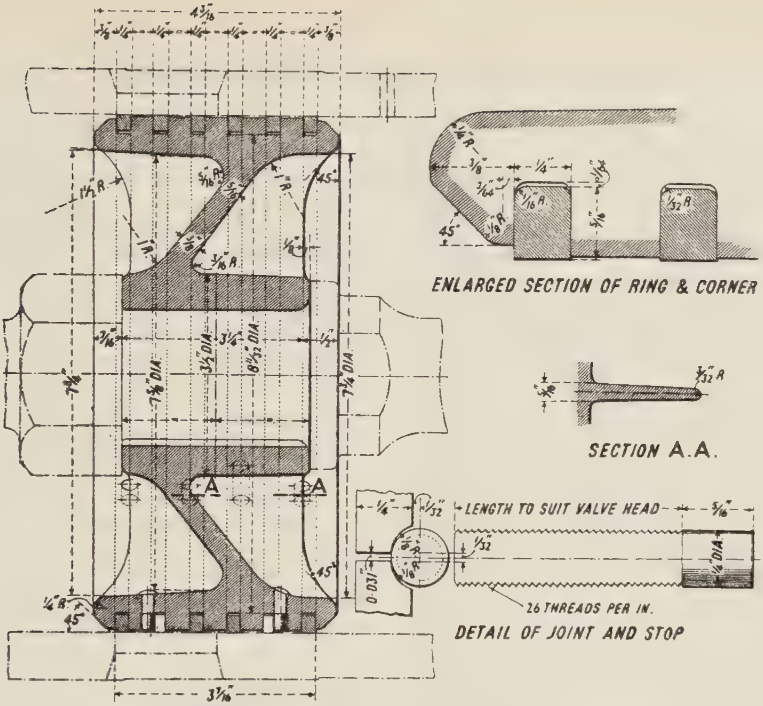


Fig. 5. — Details of piston valve head.

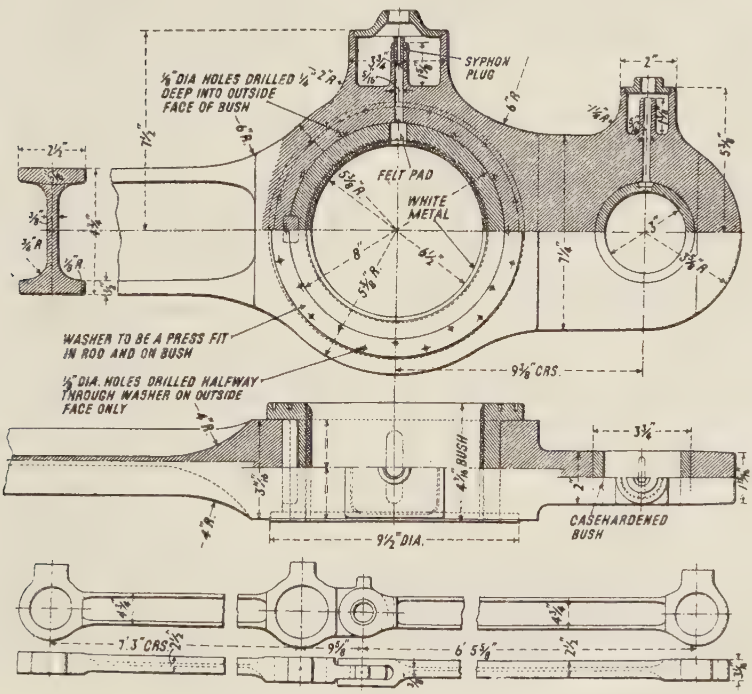


Fig. 6. — Coupling rod and fittings.

the whole engine, it is 0.24 tons, and for the whole engine per rail 3.47 tons. Exactly the same figures obtain for the new *Princess Coronation* class engine.

It is interesting to consider how this was achieved, since the arrangement of the parts is different in the two engines. The length of the outside connecting rods has been increased in the streamlined class from 9 ft. to 11 ft. between centres, and as already indicated, the inside valve gear has been eliminated. Taking the outside motion first, the weight of the reciprocating parts, including 47 per cent. of the outside connecting rod, is 673 lb. per cylinder in the *Coronation* engine, as against 676 lb. in the *Princess Royal.* It has been found possible by the use of Vibrac steel to produce an 11-ft. connecting rod some 7 lb. lighter than the 9-ft. rod of the earlier engine, which was of manganese-molybdenum steel, the weight of the former being 366 lb. The weight per cylinder of the inside reciprocating parts is 640 lb., including 40 per cent. of the inside connecting rod weight, as against 715 lb. in the *Princess Royal.* This reduction is due to the absence of inside valve gear and parts attached to the crosshead, and also due to a lighter inside connecting rod made of Vibrac steel of fluted section. The inside and outside connecting rods of the *Coronation* engine are shown in figures 7 and 8. The coupling rods are also of Vibrac steel, of fluted section. A saving in weight of 412 lb. on the set of four rods was obtained, compared with the previous engine, but it must here be stated that the length between the outer centres has been reduced from 15 ft. 3in. to 14 ft. 6 in., the weight per engine of the coupling rods, complete, being 908 lb. These rods are also illustrated (fig. 6). The lighter weight of the revolving parts is naturally reflected in a reduction in the balance weights carried in the wheels, and to sum up the effect of the Vibrac steel, and the re-design made possible, it may be stated that a total saving in weight of approximately 1 000 lb. was obtained in the reciprocating and revolving parts. The steel named gives a breaking strength of 50-60 tons per sq. in., with an elongation of 20-25 per cent., and a value of over 40 lb. in the Izod impact test.

The steel is of the well-known nickel-chromium-molybdenum type, which is forged and heat treated with a test bar attached. The heat treatment consists of oil quenching from a temperature of 840° C., followed by tempering at a visible red heat from 650-670° C., in order to relieve the hardening stresses, and the rods are subsequently allowed to cool in air from the tempering temperature. As this steel contains certain proportions of molybdenum, it is free from temper brittleness. It has been found, when certain details are quenched from the tempering temperature, that on machining there is a release of stresses which causes warping in the detailed part, and this has been obviated by the method described. This steel, which has high tensile values, is admirably suited for the stresses occurring in locomotive coupling and connecting rods. It is interesting to note that in machining these rods, the increased tensile strength made it necessary to reduce the machining speeds and feeds by about 20 per cent., as compared with the practice in plain carbon steel components.

Axles, wheel centres, and tyres.

The axles for the locomotive were made to the L. M. S. R. standard specification, which calls for an acid open-hearth steel containing not more than 0.04 per cent. of sulphur and phosphorus. A tensile breaking strength of 35-40 tons per sq. in. is called for, with an elongation of not less than 25 per cent. with 35 tons breaking strength, or 20 per cent. with 40 tons breaking strength, the elongation being measured on a gauge length of 3 in. In addition, a falling weight test on a selected axle is under-

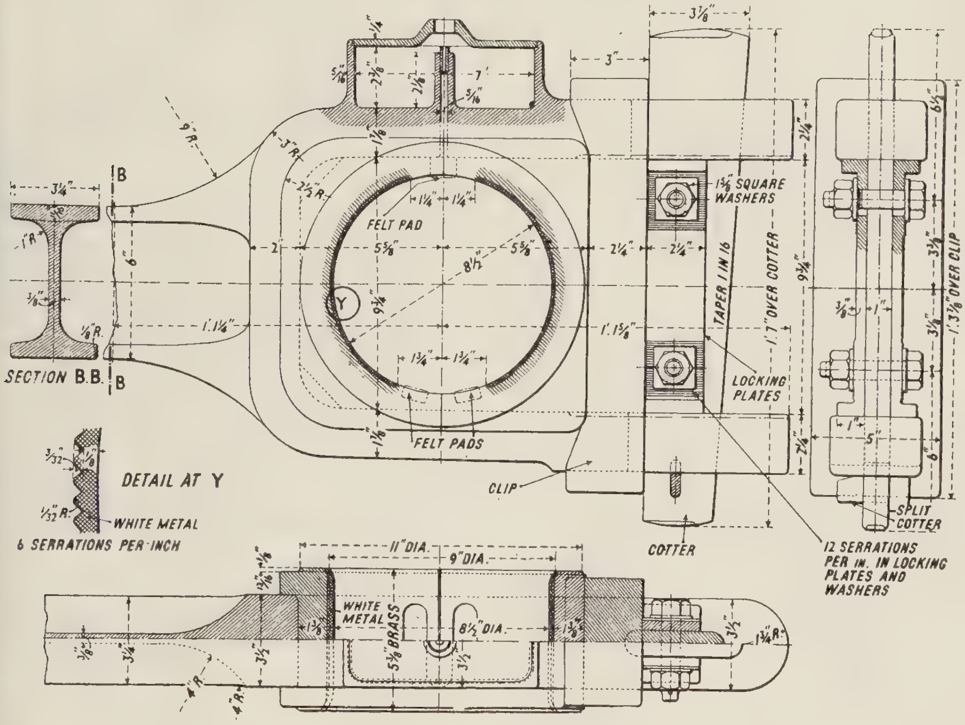


Fig. 7. — Inside connecting rod big end.

taken, in which the axle is placed upon bearings, and must withstand, without fracture, five blows from a weight of one ton falling from a height of 35 ft., the distance between the points of support being 5 ft.

Representative actual test figures for steel for this purpose, are as follow :

Breaking strength . .	37.58 tons per sq. in.
Elongation on 3 in. .	28.3 per cent.
Ratio yield point to breaking strength .	61.2 »
Contraction of area .	54.2 »

Chemical analysis :	Per cent.
Carbon	0.26
Silicon	0.211
Manganese.	0.85
Sulphur.	0.033
Phosphorus	0.030

In the falling weight test as above specified, the deflections produced by each successive blow were as follows :

1st blow	3 1/2 in.
2nd blow	Straight.
3rd blow	3 3/16 in.
4th blow	Straight.
5th blow	3 5/16 in. without fracture.

The axles are oil treated at the makers' works. In order to save weight, the axles are bored out along their axes, and the following particulars give the size of the holes and the weight saved :

—	Diam. of hole.	Weight saved.			Actual weights.		
		Cwt.	Qr.	Lb.	T.	Cwt.	Qr.
2 : bogie	2 in.	1	0	9	...	9	0
1 : 1st coupled	3 in.	1	0	9	2	4	3
2 : 2nd and 3rd coupled	4 1/2 in	5	2	15	1	1	2
1 : pony truck	3 in.	1	2	13	...	8	3
Total.		9	1	18	4	4	0

From this, it will be seen that nearly 1/2 ton was saved by boring the six axles of the locomotive alone. The process of boring out the axles was undertaken on a special lathe on which the holes were bored throughout the entire length of each axle. A special high-speed steel stepped cutter was used for the operation of rough boring, at a speed of 54 r.p.m. with a feed of 0.228 in. per min. The hole was then finished with a four-cutter reamer at a speed of 8 r.p.m., and a feed of 0.37 in. per min. The hole was then finished with a four-cutter reamer at a speed of 8 r.p.m., and a feed of 0.37 in. per min. It was found necessary to remove the steel chips with a forced lubricant on the tool at a pressure of 80 lb. per sq. in. The axles were then finished off in the grinding machine, where 0.15 in. of metal was removed from the diameter of the wheel seats and journals. Finally, the keyways were cut, and the axles were then ready for the fitting of the wheel centres. This process is shown in figure 12.

The next items to be considered are the wheel centres; the metal for these, as well as for the other steel castings required, was melted in Sesci pulverised-fuel rotary furnaces (*), using charges consisting of recovered steel scrap. The moulding sand was prepared in a Baillot sand-mixing plant, and the moulds dried in temperature-controlled ovens operated with Hermann heating elements; the castings were annealed in pulverised-fuel furnaces fitted with a pyrometric outfit.

The metal was manufactured to give a tensile strength of 26 tons per sq. in., to 20 per cent. minimum elongation, the sulphur and phosphorus contents being limited to 0.06 per cent. A low carbon steel was found to satisfy the specified physical requirements, and below are typical results of the tests of the above practice :

—	Cast C-9-64 Per cent.	Cast C-9-65 Per cent.	Cast C-9-37 Per cent.
Carbon	0.20	0.18	0.20
Silicon	0.318	0.320	0.280
Manganese	0.70	0.63	0.64
Sulphur	0.054	0.054	0.058
Phosphorus	0.042	0 047	0.041
Tensile, tons per sq. in.	28.80	27.80	29.00
Elongation, per cent.	30.00	34.00	35.00
Contraction of area, per cent.	42.00	54.80	52.40

(*) The installation of these furnaces at the L. M. S. R. Crewe works was described in *The Railway Gazette* dated September 25, 1936.

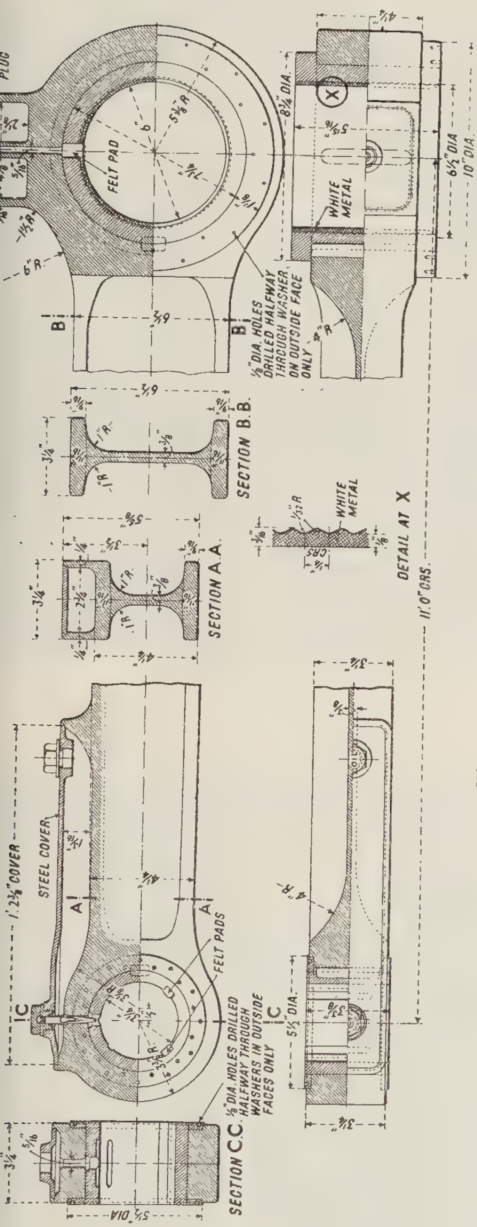


Fig. 8. — Outside connecting rod.

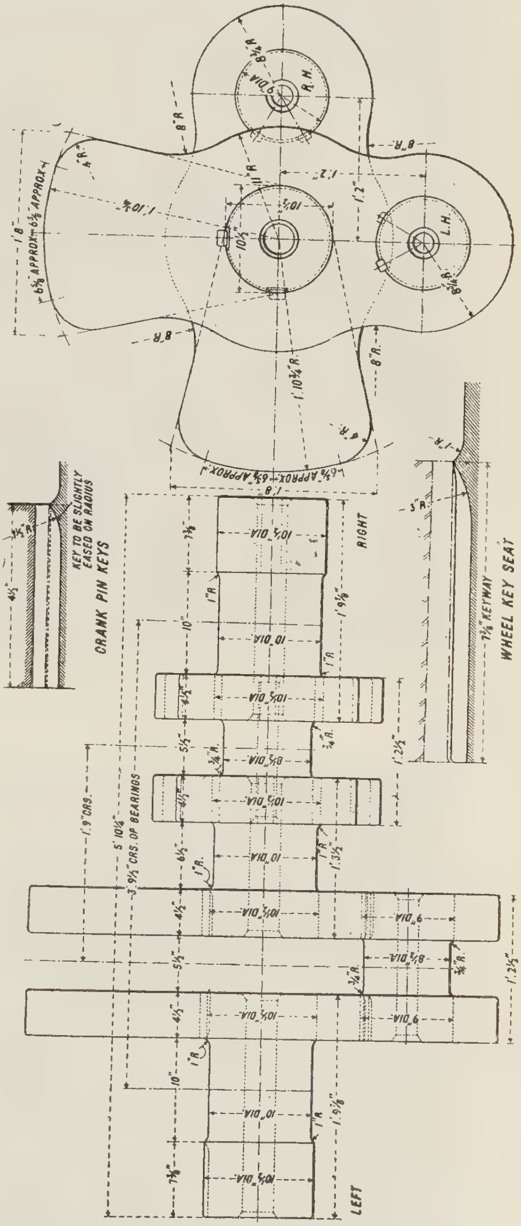


Fig. 9. — Built-up balanced crank-axle.

The bend test pieces passed through 180° without fracture.

The coupled wheel tyres of the engine are of acid steel, 6 ft. 2 3/4 in. inside diameter before machining. A typical test result of this material is given below :

—	Specified.	Actual.
Breaking strength, tons per sq. in. . .	50/55	53.37
Elongation, per cent.	18/15	21
Contraction of area, per cent.	—	33.4
Carbon	—	0.52
Silicon.	—	0.298
Manganese	—	0.72
Sulphur	0.04 max.	0.031
Phosphorus	0.04 max.	0.028

In addition to the foregoing, falling-weight and impact tests are called for in L. M. S. R. specifications. In the former, every tyre selected for test is to be placed in a running position, with the tread resting on a block of metal of not less than 5 tons weight, supported on a rigid foundation; it must withstand, without fracture, blows from a falling weight of one ton, the weight being allowed to fall freely from heights of 10, 15, 20, 25, and 30 ft., until the deflection of the tyre corresponds to that given by the formula $\frac{(D\text{-}3\ S)^2}{45T^2}$, where :

D = internal diameter of tyre;
T = thickness at middle of tread;
S = depth of snip.

In a representative actual test on these lines, 14 successive blows were withstood without fracture, the final deflection being 12 1/4 in. The impact test is made on a standard Izod test piece, 10 mm. square, cut as close to the surface of the tread as possible. The results of this test are taken for information only, and are not specified beforehand. On actual test, a figure of 4 ft.-lb. represents an average result.

The requirements of the bogie and pony truck tyres are slightly different as regards physical characteristics, and a typical test result for this material, is as follows :

—	Specified.	Actual.
Breaking strength, tons per sq. in. . .	56/62	60.5
Elongation, per cent.	13/11	15.5
Contraction of area .	—	24.6
Carbon	—	0.61
Silicon.	—	0.31
Manganese	—	0.56
Sulphur	0.04 max.	0.030
Phosphorus	0.04 max.	0.031
Nickel	—	0.13
Chromium	—	0.57

Falling weight and Izod impact tests are taken in the same way as on the coupled wheels. The heat treatment consisted of re-heating to 830° C., quenching in oil, and tempering to 650° C.

Machining wheel centres and tyres.

The 6-ft. 3-in. diam. wheel centres were machined on vertical boring machines, using tools tipped with Stellite 40, for roughing out at a speed of 30 ft. per min., with a feed of 0.074 in. and 3/4 in. depth of cut. In oder to obtain a satisfactory finish, Cutanit tipped tools working at a speed of 627 ft. per min., a feed of 0.018 in., and 0.015 in. depth of cut, were used. After the keyways had been cut, the wheel centres were pressed hydraulically on their respective axles at a pressure of not less than 10 tons, and not greater than 12 tons per in. diam. of axle. The wheels were then mounted in a quartering machine, where the crank-pin holes were bored out to the correct angle prior to fitting of the crank pins and fixing the tyres.

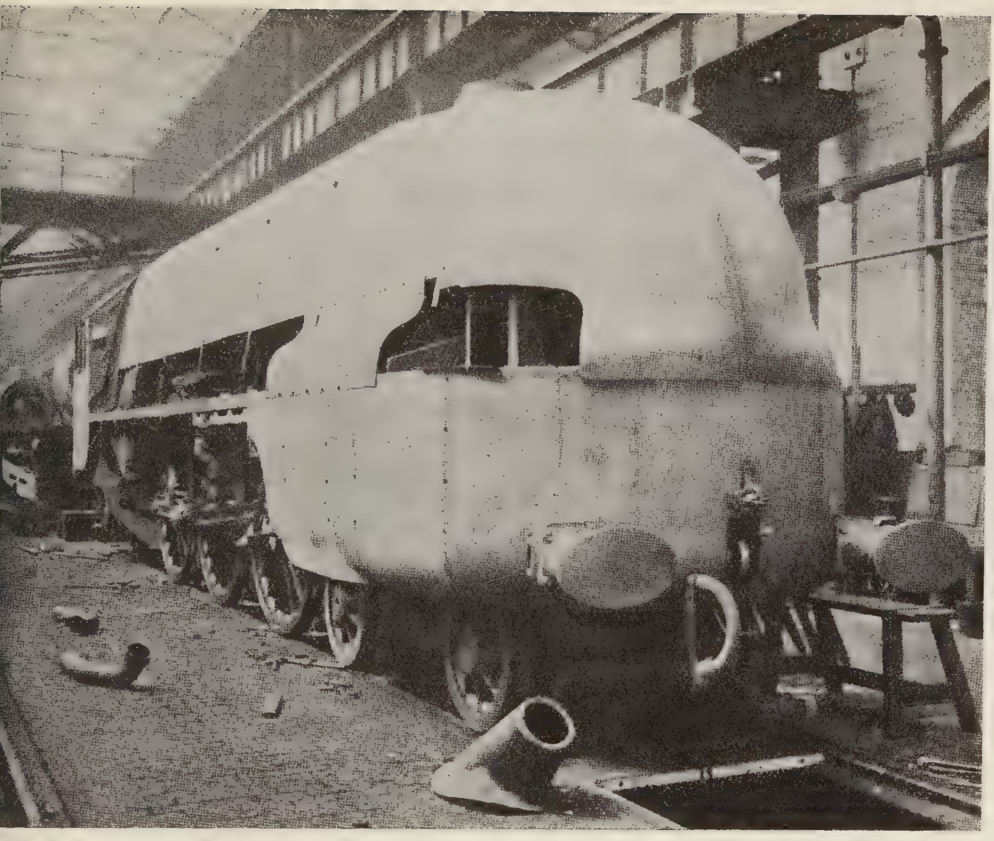


Fig. 10. — Engine partly completed in Crewe works. Streamlining casings in course of erection.

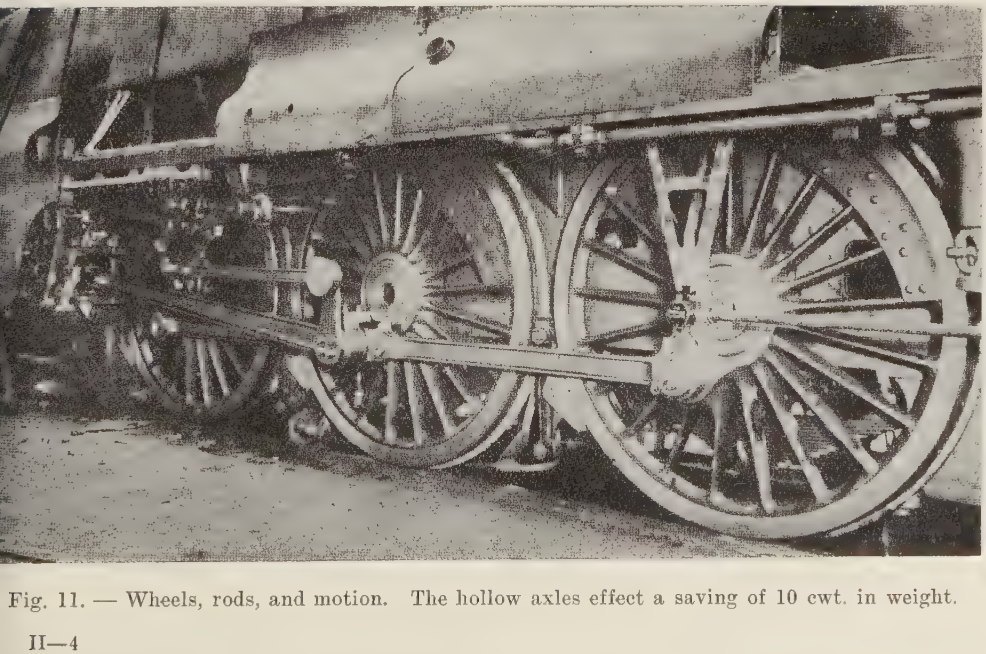


Fig. 11. — Wheels, rods, and motion. The hollow axles effect a saving of 10 cwt. in weight.

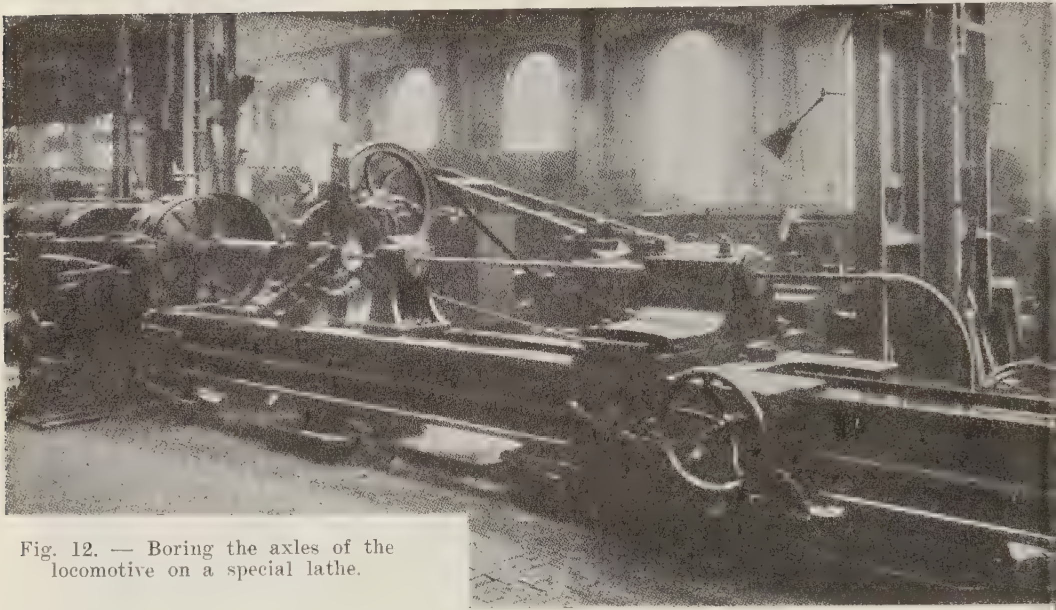


Fig. 12. — Boring the axles of the locomotive on a special lathe.

The tyres were machined on a vertical boring machine, the rough boring operation, including the groove for the Gibson ring, being done in one cut at a speed of 53 ft. per min., feed of 0.065 in. and 3/16 in. depth of cut; Stellite-40 tipped tools were again used for this work. The finishing cut was performed with Cutanit tools at a speed of 600 ft. per min., feed 0.054 in., and cut of 0.015 in. The tyre was bored smaller than the wheel centre, to the formula :

$$\frac{D}{1\,200} + 0.005 \text{ in.}$$

where D is the inside diam. of the tyre in inches.

It was then expanded by means of gas heaters, after which the wheel centre was placed in position, the Gibson ring fitted, and the tyres turned on the tread.

The ribbed silico-manganese steel used for the manufacture of the springs was received from the contractors in long bars in the « as rolled » condition, and complied with the undernoted specification as regards composition :

C	Si	Mn	S	P
per cent	per cent	per cent	per cent	per cent
0.5-0.6	1.8-2.0	0.7-1.0	0.04 max.	0.04 max.

The spring plates were cold sawn to length, and the longer plates drilled to take the spring link, the shorter ones being speared at the ends. After heating to approximately 850° C., they were bent to the required camber, and cooled to below 600° C. For heat treatment, two town gas-fired furnaces were used, each equipped with a recording pyrometer for temperature control. After soaking at 890° C.-900° C. for about 15 minutes, the plates were quenched in linseed oil. Thereafter they were tempered in a furnace standing at 800° C. for 4 minutes for 5/8-in. plates, and 3 1/3 minutes for 1/2-in. plates. A hazel stick was used on the plates after withdrawal, to ensure proper temperature conditions by showing heavy sparking; or alternatively, the

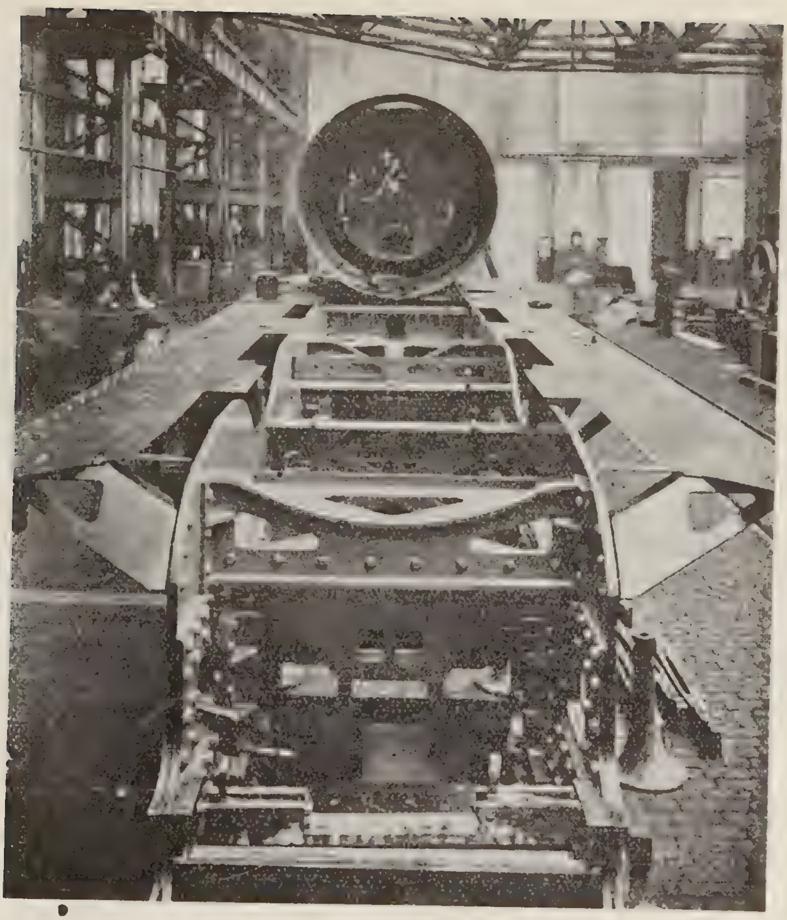


Fig. 13. — View of frames from above showing stretchers and brackets.

Fig. 14. — The main frames of the engine are 1 1/8 in. thick and made of a special high tensile acid steel.

temperature of the surface of the plate was checked by a contact pyrometer to come within the range 450° C.-500° C.

In these cases, 3 per cent. of the plates are tested, a length of 2 ft. 6 in. being cut off from each plate selected, and cambered to a radius equal to 80 times the thickness, and then hardened and tempered. The test piece, after being pressed straight once, and the camber noted, must stand being pressed straight again six times in quick succession without showing any permanent set. As an example, in a plate 5/8 in. thick, the required camber is 2 1/4 in., and the minimum camber after the six successive blows referred to, is 2 in.

Thereafter, the plates were assembled, held together by a loose band, tested, dissembled, shot-blasted to remove scale, examined for flaws, dressed with petroleum jelly, and reassembled. The spring buckle was then fitted, and the tightening key inserted and spot welded to ensure that no looseness would be experienced in service.

The essential differences in manufacturing methods with silico-manganese steel springs as compared with plain carbon steel components, show that whereas the plates for the former are cold sawn and oil quenched before tempering, the latter are sheared and water quenched prior to tempering. In addition, the buckles are wedged in position in manufacturing the silico-manganese components, whilst for the plain carbon springs, the buckles are shrunk on. The advantage of the hardening in oil instead of water, is the elimination of water quenching cracks. Relatively thick sections of silico-manganese steel can be so dealt with, whereas plain carbon steel will not harden sufficiently in oil when the section exceeds a certain low minimum value.

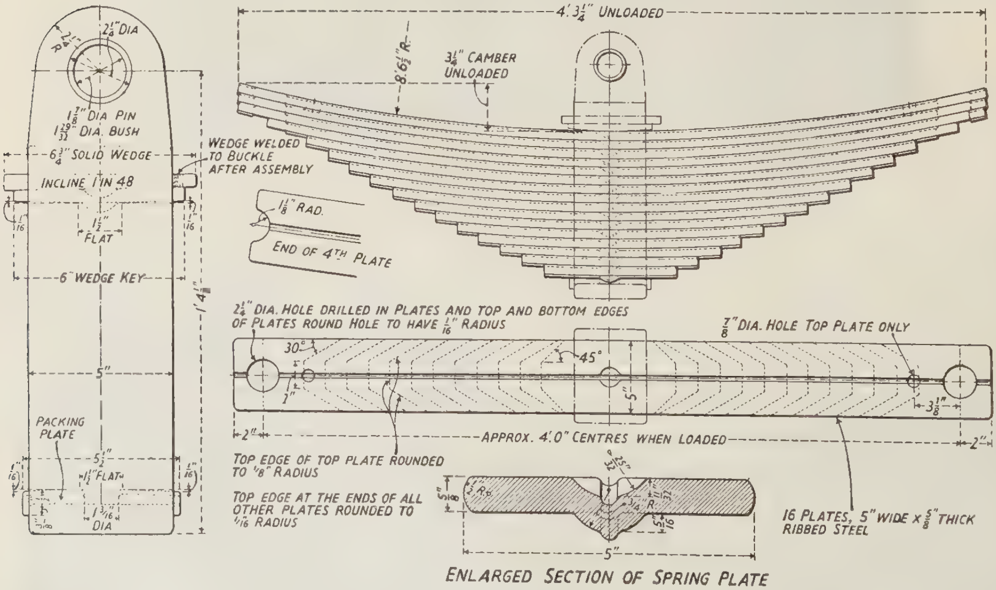


Fig. 15. — Details of coupled wheel springs. Ribbed silico-manganese steel is used.

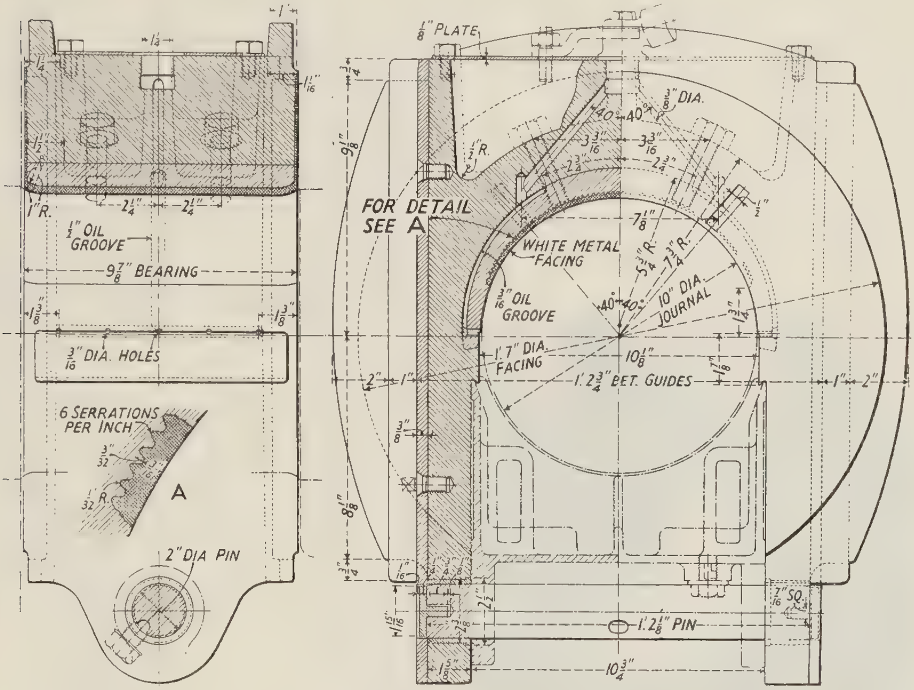


Fig. 16. — Details of axlebox for coupled wheels.

Other advantages of this steel for springs, may be given as follow :

(1) Silico-manganese steel is more foolproof as regards heat treatment and manufacture.

(2) Oil-quenched silico-manganese steel gives less distortion than water-quenched carbon steel.

(3) The elastic limit of silico-manganese steel is higher, and this should be reflected in increased life.

Bearing metals.

It is essential that bearing metals for locomotives of this kind should have good fatigue resistance, and consequently they are of the high-tin base type. The analysis of the metal used on the big and little ends of the connecting rods and the axlebox bearings, is as follows :

Tin	85	per cent.
Copper	5	»
Antimony	10	»

The lining of details is a carefully controlled operation, all white-metal pots being fitted with thermocouples and recorders, and in some cases thermostatic control. The bath used for the tinning of smaller details such as coupling-rod bushes, is also controlled by a thermocouple. This is in accordance with the general methods employed on L. M. S. R. locomotives, and was followed in the case of the *Princess Coronation* engines.

The tinning medium used is an alloy of the following composition :

Tin	59.0	per cent.
Antimony	9.5	»
Copper	3.0	»
Lead	28.5	»

This was arrived at after considerable investigatory work. An interesting test has been developed in connection with the adhesion of the white metal to the

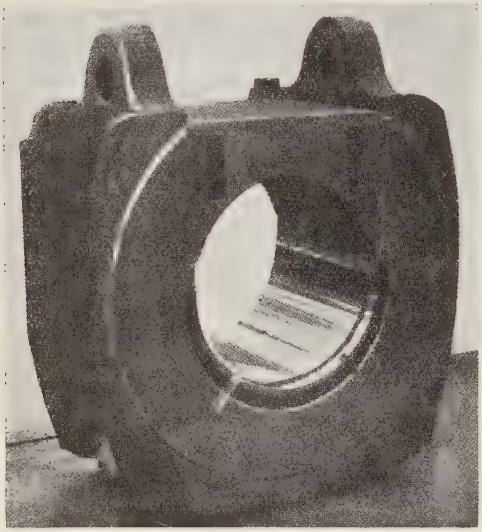


Fig. 17. — Perspective view of axlebox after machining.

brass shells. This test is made by removing a strip of the actual detail, and subjecting it to blows on the Izod testing machine. Periodic checks are made in order to see if the standard of tinning and melting is being obtained.

Manganese-molybdenum steel forgings.

Certain component parts on the engine subject to high stress or shock loading, are made of manganese-molybdenum steel, which is particularly suitable for this purpose. The parts on which this material is used are as follow :

(1) Brake hangers, levers, pull rods, and cross beams.

(2) Spring bolts and spring adjusting links.

(3) Reversing shafts and die blocks.

(4) Slidebar bolts.

(5) Bolts securing leading crank pin washers.

The specification calls for the following characteristics :

Physical tests :

Breaking strength, tons per sq. in.	40-45
Elongation, per cent. on 2 in. gauge length	25-20
Ratio of yield point to breaking stress, per cent.	75 min.

Chemical analysis :	Per cent.
Carbon	1.5-2.0
Silicon	0.25
Manganese	1.5-1.7
Sulphur	0.04 max.
Phosphorus	0.04 max.
Nickel	0.3-0.5
Molybdenum	0.2-0.3

An Izod impact test of at least 70 ft.-lb. is called for, and in the actual material produced, Izod impact figures of over 100 ft.-lb. are frequently obtained.

This may be said to complete the description of the principal metallurgical characteristics in so far as they apply to the locomotive itself, and as has already been intimated, the same principle and methods are followed in the case of certain other locomotives built by and for the L. M. S. R., in accordance with the instructions and requirements of Mr. W. A. Stanier, the Chief Mechanical Engineer.

Tender of welded construction.

Before concluding our article, it is necessary to make some brief mention of the system followed in building up the

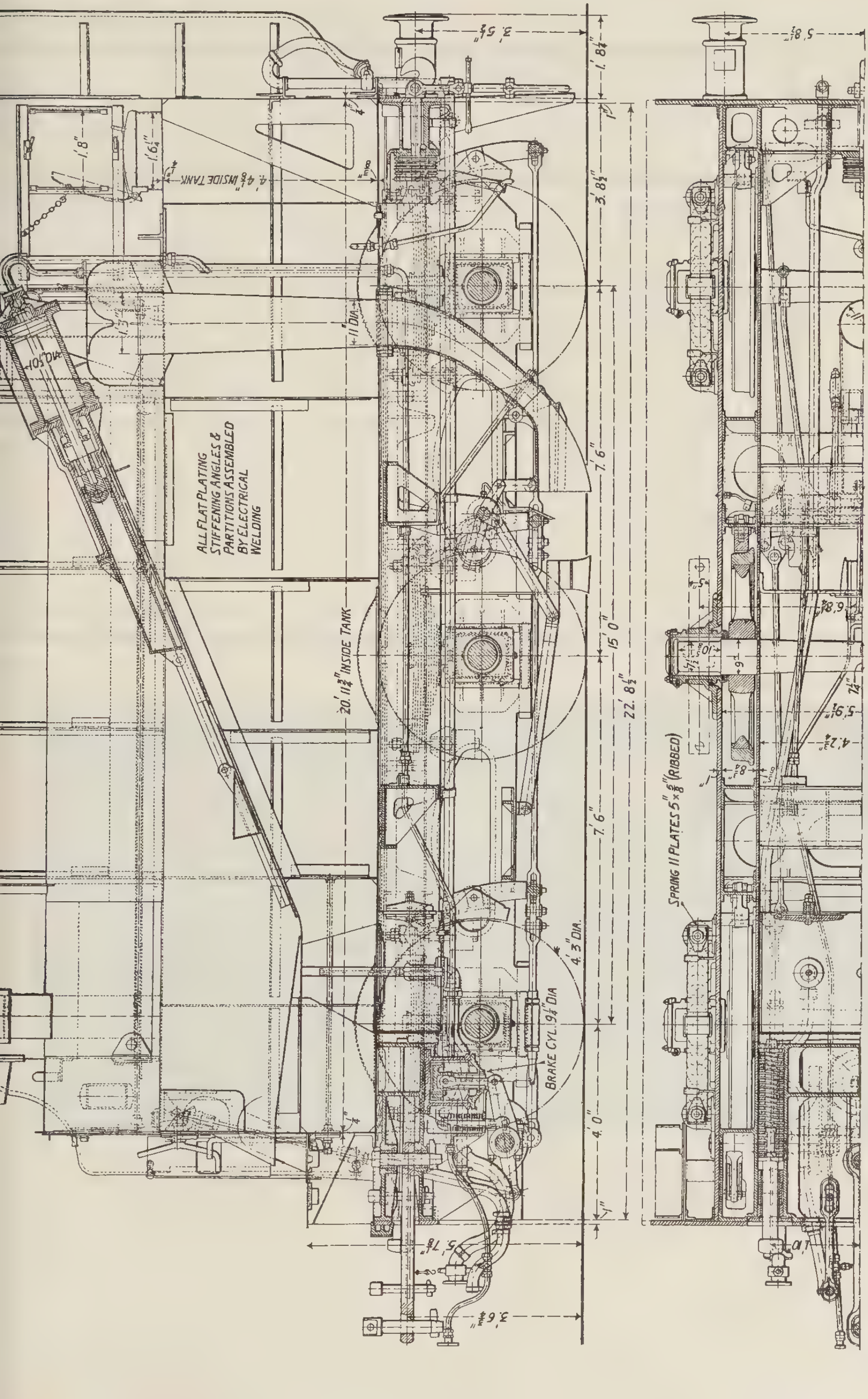


Fig. 18. — Detail of welded tender showing coal pusher and water pick-up apparatus.

TABLE IV. — **Manganese-molybden**

Description of material.	Maker.	Cast. No.	Breaking stress, tons per sq. in.	Elongation, % on 2 in.	Ratio y.p./b.s., %	C of
Adjusting links. . . . / Adjusting screws . . .	Brown Bayley's Steelworks Limited.	B. 2150	40.0	29.0	83.0	
Pull rods . . . . . . / Spring bolts	S. Fox & Co. Limited.	N. 5859	42.6	27.0	82.2	
Crossbeams	Brown Bayley's Steelworks Limited.	A. 1822	40.0	28.0	82.0	
Die blocks.	Colvilles Limited.	4C. 6045	38.6	26.0	81.4	
Reversing shafts . . .	Do.	4C. 6277	45.5	22.0	80.0	
Specified		...	*40/45*	*25/20*	*75 min.*	
Brake hangers	S. Fox & Co. Limited.	W. 360	44.0	27.0	79.1	
Brake levers	Colvilles Limited.	4C. 6277	45.4	25.0	83.7	
Spring bolts	Brown Bayley's Steelworks Limited.	E. 7843	44.0	28.0	82.0	
		»	42.0	28.0	83.4	
»	»	B. 2150	41.0	29.0	78.0	
Bolts	Colvilles Limited.	D. 8041	42.0	29.0	83.5	
		»	43.0	28.0	83.8	
Specified		...	*40/45*	*25/20*	*75 min.*	

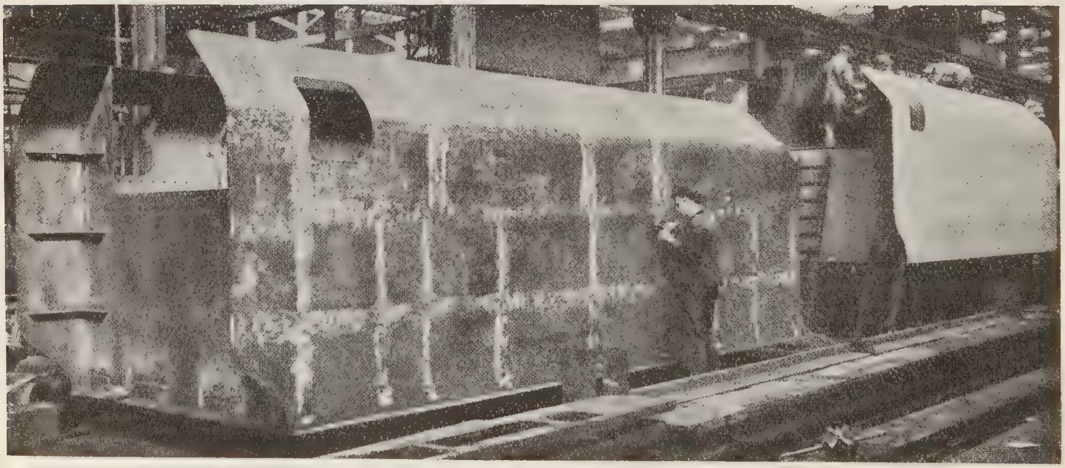


Fig. 19. — Welded tenders for streamlined express engines in the Crewe shops. — In foreground, removing surface irregularities with portable grinding machine.

, manufactured at Crewe works.

end test.	Chemical analysis.							Izod impact test.		
	C %	Si %	Mn %	S %	P %	Ni %	Mo %	Ft.-lb. 1	2	3
E.T.W.F.	0.20	0.24	1.54	0.039	0.035	0.39	0.24	111	104	107
Do.	0.19	0.245	1.54	0.028	0.040	0.65	0.19	98	96	102
Do.	0.17	0.22	1.61	0.038	0.035	0.36	0.26	91	87	104
Do.	0.155	0.110	1.56	0.029	0.029	0.49	0.26	...	...	...
Do.	0.18	0.16	1.69	0.034	0.038	0.71	0.23	...	...	...
E.T.W.F.	*0.15/0.20*	*0.25*	*1.5/1.70*	*max. 0.040*	*max. 0.040*	*0.3/0.5*	*0.2/0.3*	...	...	*70 min.*
E.T.W.F.	0.20	0.236	1.66	0.026	0.038	0.50	0.22	106	108	112
Do.	0.18	0.16	1.69	0.034	0.038	0.71	0.23	72	73	93
Do.	0.18	0.23	1.58	0.039	0.033	0.49	0.29	108	109	112
	...	...	...	...	...	...	...	115	108	107
Do.	0.20	0.24	1.54	0.039	0.035	0.39	0.24	99	105	98
Do.	0.18	0.25	1.52	0.034	0.033	0.46	0.28	115	114	115
	...	...	...	...	...	...	...	109	118	116
E.T.W.F.	*0.15/0.20*	*0.25*	*1.5/1.70*	*max. 0.040*	*max. 0.040*	*0.3/0.5*	*0.2/0.3*		*70 min.*	

tender, in which welding was adopted on a fairly wide scale. The tender tanks are welded throughout with an electrode of the shielded-arc type, and a special layout was arranged at Crewe for progressive working, the underlying principle being to keep vertical and overhead welding to a minimum. With the exception of the vertical corner joints, all the welding was done at a single pass. At the first berth or stage, gussets and stiffening angles were welded to the back and side plates, the well was built up, and the door plate and tool cupboards built into a single unit. At the second berth, the bottom plate was inverted, and had the well and delivery pipe flange welded on before being turned right way up to have the splashers welded on. The bottom was then lifted on to the third berth, where it was clamped down, and had the back, front and side plates welded to form a complete box section which was sufficiently rigid to withstand lifting on to the next berth. Here, the top and sloping plates were welded into position, and the internal stiffening bars also welded in place. This completed the internal welding, and, at the last berth, the tool tunnel, slope plate extensions, platform plate, and other parts were welded on.

Where it was necessary to obtain water-tightness, the welding was continuous, but elsewhere intermittent welding was adopted. With this procedure, distortion was kept to a minimum, but there was an inherent distortion on the side plates, where the gussets were welded on, causing small ridges to form on the outside of the plate. These ridges were ground off by portable hand-operated grinding tools when the tank was completed. The saving in weight due to using a welded tank instead of the usual riveted tank, is approximately one ton.

[621. 135.2 & 625. 214]

Testing machines for the measurement of the coefficients of friction of lubricants and anti-friction alloys,

by I. HAGUENAUER,

Honorary Engineer, Est Railways (France).

Direct measurements having as their object the computation of the coefficient of friction of lubricants, particularly those for use on railway rolling stock, were first undertaken quite a long time ago.

As far back as 1891, the Est Railway Company carried out comparative tests using lubricating mineral oils (petroleum residues) of various types and qualities, with a view to establishing a law governing the temperature rise of the bearing and the oil, in a freight wagon axlebox, in terms of the speed and the load. The coefficients of friction were measured at the same time and their variations plotted in graph form.

I. — EARLY MACHINES.

(*a*) *Napoli oil-testing machine.*

The machine used for the above mentioned experiments was devised by Mr. Napoli, Chief of the Est Railway Company's Laboratory. It reproduced service conditions in regard to the nature and dimensions of the contacting surfaces (journal and bearing), the method of lubrication, the intensity of pressures, and the speeds (fig. 1).

The coefficient of friction f was determined from the relationship between the opposing tangential force F exerted at the circumference of the journal and the load applied to the bearing. To obtain f, it was sufficient to determine F.

Let r denote the radius of the journal in metres, and T the opposing effort, in kgr., applied by a tension spring to a lever, at a point l metres distant from the centre of the journal. This lever is integral with an articulated stirrup

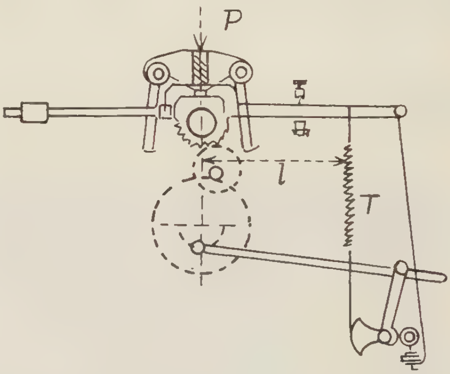


Fig. 1.

which, in embracing the axlebox, is subjected to the frictional drag of the journal. Then if P is the total load, in kgr., upon the journal, we have

$$F \times r = T \times l$$

whence

$$F = \frac{T \times l}{r}.$$

Now

$$F = f \times P$$

and so

$$f \times P = \frac{T \times l}{r} \text{ that is to say } f = \frac{T \times l}{r \times P}.$$

This last formula was used to determine the coefficients of friction.

The Napoli machine was also fitted with an automatic device for recording bearing pressures.

One serious drawback inherent in this apparatus was the difficulty experienced in centring accurately the load applied to the journal. This hindered the setting up of identically similar conditions of test for successive trials and prevented strict comparison of the results obtained. This defect originated principally in the elastic deformation of the yoke which embraced the bearing, as a result of which the centre line of the knife edges passed below the axis of the journal. This introduced a disturbing couple which interfered with the evaluation of the frictional torque.

(b) The Galena Company's machine.

It was, however, found possible to avoid the foregoing difficulty by having recourse to more complicated but more robust apparatus.

The design outlined in figure 2 provided for the loading of the bearing through a system of beams and connecting links A, B, C, so contrived as to ensure that the resultant of the applied forces should at all times pass through the axis of the journal, regardless of the displacement of the bearing.

Regulation of the load was effected by means of a right- and left-handed nut, D, which put into tension a spring R fixed at one end of a lever, E, the frictional forces being at all times automatically balanced by the cursor of a steel-

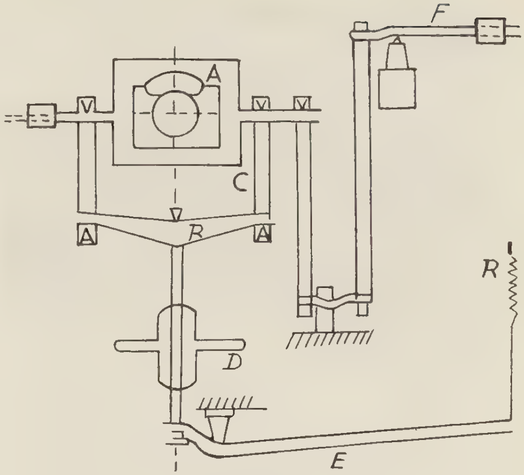


Fig. 2.

yard, F, attached to the beam which is integral with the bearing.

(c) Jonet's apparatus.

Towards 1900, a similar but simpler

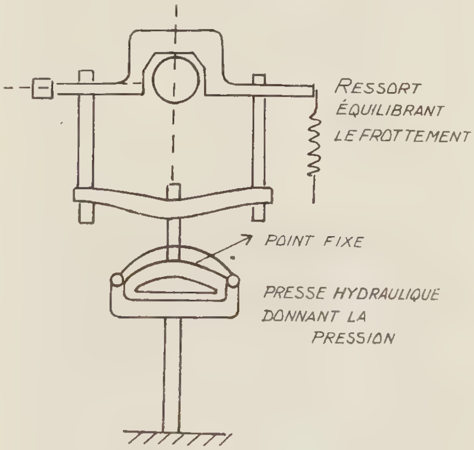


Fig. 3.

Note. — Ressort équilibrant le frottement = Spring, balancing frictional resistance. — Point fixe = Fixed connection. — Presse hydraulique donnant la pression = Hydrauilc press for leading.

mechanism as outlined in figure 3 was experimented with by Mr. Jonet, then Inspector to the Est Company.

(*d*) *Gosserez machine.*

About the same time Mr. Gosserez, an engineer of the Est Railway, designed a machine based upon a principle which differs from the foregoing and is to be seen in the Martens apparatus at the « Conservatoire National des Arts et Métiers ». Here the balanced system comprised what was in effect a pendulum capable of oscillation about the axis of the journal.

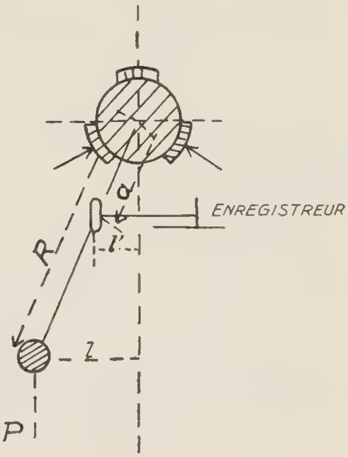


Fig. 4.

The journal was fitted with brasses to which a variable pressure could be applied. The brasses were held in a device incorporating a counterpoise which served to balance the moving system and maintain its centre of gravity on the axis of the journal (fig. 4). The greater the bearing pressure and the speed, and the more viscous the oil used, the greater is the displacement of the pendulum system due to frictional effort. The counterpoise P opposes rotation and the system swings into an oblique position corresponding to equilibrium between the forces exerted by friction and by the counterpoise. A continuous autographic recorder registered horizontal projections of the angular displacements of the pendulum.

The coefficient of friction was then evaluated as follows :

Let r be the radius of the journal;

R the distance from the centre of gravity of the pendulum to the axis of the journal;

a the distance of the recording arm from this same axis;

T the weight of the counterpoise;

l the horizontal projection of the displacement of the counterpoise;

l' the path traversed by the recorder;

N the pressured exerted on the bearing;

F the tangential frictional force at the circumference of the journal.

We have :

$$F = f \times N$$

Now

$$F \times r = T \times l \text{ (for equilibrium);}$$

Moreover

$$\frac{l'}{l} = \frac{R}{a}$$

whence

$$F \times r = T \times \frac{R}{a} \times l'$$

that is to say

$$f \times N \times r = T \times \frac{R}{a} \times l'.$$

Finally

$$f = \frac{T}{r \times a} \times \frac{R}{N} \times l'.$$

This last formula enabled the coefficient of friction f to be determined in terms of known quantities.

II. — RECENT MACHINES.

Research has been continued on the same lines in an endeavour to evolve machines which will give results of an accuracy beyond criticism. We shall now briefly describe those which to us appear to conform most closely to the requirements laid down. They are :

A. The Guillery-Haguenauer machine, of the Est Railway;

B. The machine at the Laboratory of the Isothermos Company;

C. The Woog machine, at the Laboratories of the « Compagnie française de Raffinage ».

D. The Vollet machine, at the « Conservatoire National des Arts et Métiers ».

E. The machine at the Research Station of the Reichsbahn at Göttingen.

A. — Guillery-Haguenauer machine.

This machine is inspired in principle by Jonet's apparatus previously described. It measures the coefficient of friction directly and diagrammatically records it, together with the corresponding temperature rise in a steel shaft which rotates in a bearing under variable speed and load conditions, these being similarly recorded, so that when a test is stopped after a given period, a set of four diagrams is obtained covering coefficients of friction, temperature rise, speed, and load. As these diagrams are plotted simultaneously and to the same scale, by superimposing them, an ensemble of the results of the test is obtained.

Note. — The values of the coefficients of friction may in addition be calculated by the « comparator » method later described, which was first applied to the similar machine in the Isothermos Laboratory.

(a) Principal features :

The machine (fig. 5) was built in 1924 by Messrs. Etablissements Malicet et Blin. Its essentials are :

— Firstly, a shaft, A, of special steel, to which is fitted a ground journal, B, measuring 130 × 240 mm. (5 1/8" × 9 7/16"). This shaft, which is replaceable by others of different diameters according to the test in view, is supported between two roller-bearing blocks, C. The journal rotates in a box, D, similar to those used in railway vehicles.

— Secondly, a system of links in the form of a parallelogram E, F, G, H, in which the articulated members are mounted on knife edges. The links transmit the load to the journal through a shell, I, and a bearing, J, similar to the upper half of a railway axlebox. The load is applied by a piston, K, working in a chamber, L, under pressure from a geared Guillery glycerine pump, M.

Lubrication of the journal is provided by a pad-oiler, N, held in the bottom half of the box which serves as an oil reservoir and is secured by lugs to the upper shell. The oil level is maintained constant throughout the tests.

The shaft is driven by belting and a wide range of speeds is provided.

A device comprising a reducing lever and an eccentric P enable the shaft to be displaced alternately to ensure uniform distribution of the heat developed by friction between the bearing brass and the journal.

— Four recorders are fixed to the main frame of the machine.

— The first — Z_1 — registers the speed of the shaft.

— The second — Z_2 — records the loads applied to the bearing.

— The third — Z_3 — records the temperature attained by the bearing brass, through which a hole is drilled into the white metal lining, close to the bearing surface, to receive the bulb of the recording thermometer.

— The fourth — Z_4 – registers the coefficients of friction. The device employed to this end consists of an extension of the lower yoke of the parallelogram (fig. 6). This extension carries at its extremety a pointed spindle, R, which bears upon the centre of the piston, S, which in turn deflects an elastic diaphragm, T, fixed in a small hydraulic chamber, U. The chamber communicates with both the manometric recorder Z_4 and a mercury column, V, used for balancing. An accessory attachment (1) fitted to this same extension of the lower yoke allows consecutive measurements of the coefficient of friction to be made, for each direction of rotation of the shaft.

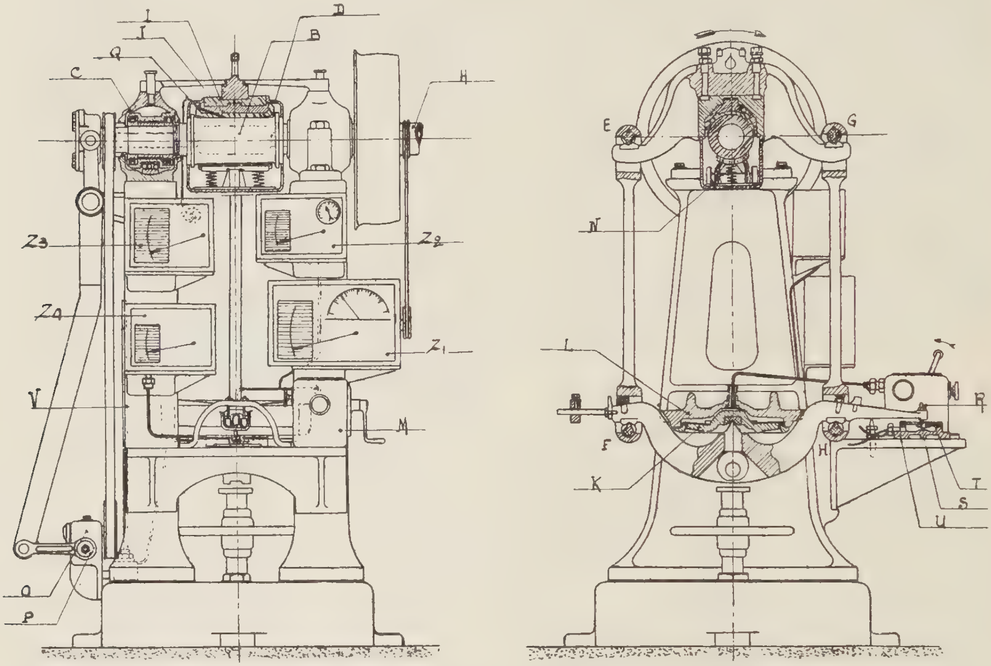


Fig. 5. — « Guillery-Hagenauer » machine.

The values of the coefficient of friction are obtained by a calculation similar to that previously worked out for the Napoli machine. The equation of equilibrium is the same :

$$F \times r = f \times P \times r = p \times l.$$

P represents the load in kgr. applied

(1) This attachment consists of a stirrup, E, fixed to the base plate, P, of the hydraulic chamber, U. In the stirrup are two centres, H, which engage two small-pistons, I, attached to two rollers, G_1 and G_2. These rollers are supported by a flexible blade, L, secured at each extremity to the bridge-piece, F, and embracing the end of the yoke as shown in figure 6.

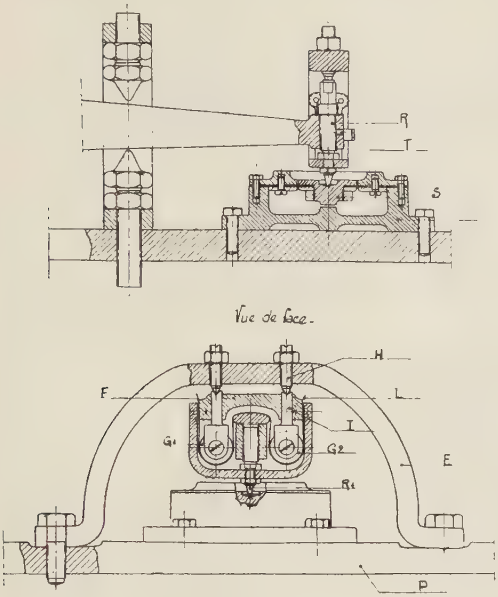


Fig. 6.

Explanation :

E. Stirrup. — F. Fork. — G1, G2. Rollers. — H. Centres. — *I*. Pistons. — L. Flexible blade. — P. Baseplate. — R, R[1] ....Pointed spindles. — S. Piston. — T. Elastic diaphragm. — U. Hydraulic chamber. — Vue de face. = Front elevation.

to the journal, and passing through its axis;

r is the radius of the journal (in metres);

F the frictional resistance (in kgr.);

l the length (in metres) of the lever arm transmitting the force of frictional resistance to the hydraulic chamber which communicates with the manometer recording frictional torque;

p is the force (in kgr.) exerted at the tip of the lever arm.

Then

$$f = \frac{l}{\mathrm{P} \times r} \times p.$$

The term $\frac{l}{\mathrm{P} \times r}$ may be represented by a constant K characteristic of the machine and f is then given by the simple equation :

$$f = \mathrm{K} \times p.$$

(b) Accessories.

The machine is fitted with additional devices (fig. 7) comprising :

1. A system for heating and cooling the shaft, by circulating hot or cold oil; any desired experimental temperature of the journal can thus be rapidly attained.

2. Automatic control of the journal temperature, which can be kept constant throughout the test.

3. A device which permits the centring of the parallelogram system, and the direct measurement of the coefficient of friction.

1. *Heating and cooling.*

For this purpose the shaft has been bored, and hollowed out at the journal. Since the pipework which serves it is fixed, special packing at either end preserves the rotating-and-sliding joint necessitated by the to-and-fro movement of the shaft. Other essential parts of the heating and cooling system are a heater, R, a cooler, S, an oil-circulating pump, P, a distributor, D, which governs the admission of hot or cold oil as required, and an expansion chamber, B.

The distributor piston, D, is actuated by compressed air under the control of an electro-valve, E. The ports in the piston allow the delivery of either hot or cold oil, and are so disposed as to allow the passage of hot oil only when air is admitted to the distributor.

2. *Automatic regulation.*

Automatic regulation comes into operation once the stipulated temperature limit has been attained. When the recorded temperature tends to exceed this limit, cold oil flows through the shaft and, in the opposite case, hot oil. Regu-

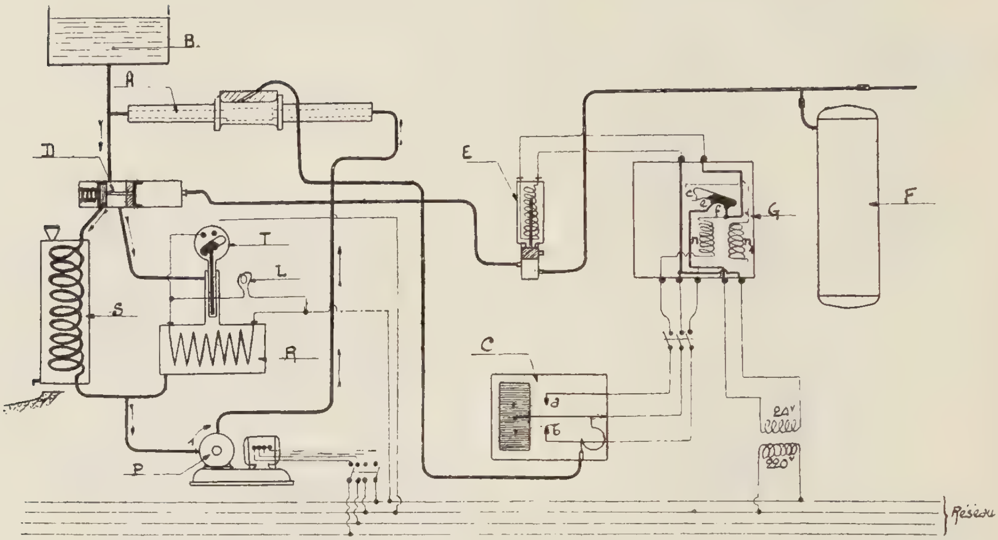


Fig. 7.

A. Shaft to be heated. — B. Expansion chamber. — C. Temperature recorder. — D. Oil distributor. — E. Electro-valve. — Auxiliary reservoir. — G. Richard relay. — L. Pilot lamp. — P. Pump. — R. Heater. — S. Cooler. — T. Thermostat.

lation is effected by the movements of the stylus of the temperature recorder C which works between two adjustable cursors *a* and *b*. Contact of the stylus with either of these opens or closes circuits which bring into action the oil distributor, D, through the agency of the electro-valve, E, which is itself controlled by a relay, G, comprising two electro-magnets and a mercury cut-out.

Current is provided by a 220-240 volt single-phase transformer, and the circuits controlled by the electromagnet are opened or closed according as the stylus bears on one or other of the contacts *a* and *b*.

A reservoir, F, connected by a branch pipe to the air main, and fitted with a check valve, ensures a reserve capacity of air during the test.

The working of the control system is shown diagrammatically by figure 7. It gives rise, in short, to a series of temperature variations. The corresponding temperature record is a sinusoidal curve the ordinates of which may be altered with respect to the desired temperature level, regulation being effected by varying the spacing of the two contacts *a* and *b*.

3. *Centring of the parallelogram.*

In the interests of accuracy it is essential that the parallelogram be centred with great precision, otherwise the readings taken when estimating the frictional torque will be subject to errors arising from a disturbing couple, as was the case with the Napoli machine.

In order to avoid this, means are provided for dead-centring the parallelogram so that the load shall act precisely through the centre line of the journal.

To this end, the upper yoke *a* of the parallelogram (fig. 8) is capable of lateral displacement with respect to the upper shell of the axlebox through the agency of two handwheels, BB, mounted

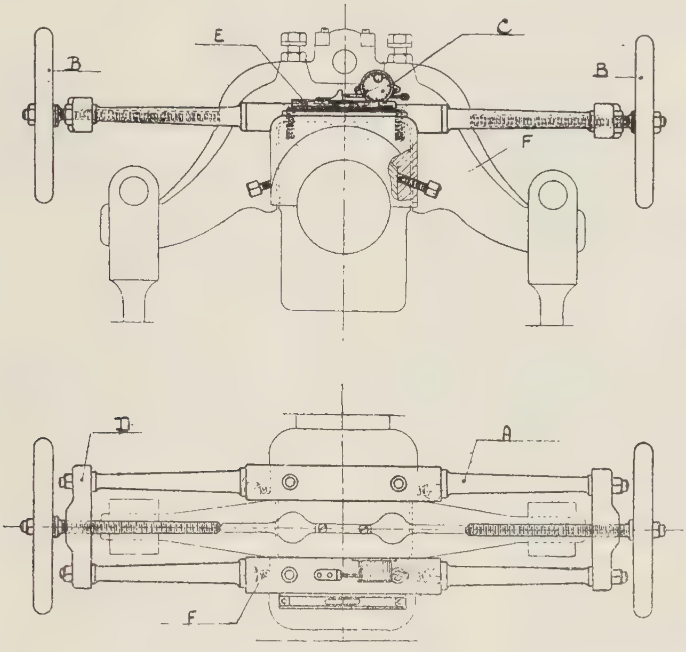


Fig. 8.

A. Tiebar of stirrup. — B. Handwheel and locking screw. — Comparator, reading to 1/100 millimetre. — D. Crossbar. — E. Spirit level. — F. Bearing locking-screw.

on a stirrup which is built into the top of the box. A comparator, C, reading to 1/100 mm., integral with the yoke, has its spindle resting against a projection which is integral with the stirrup and, therefore, with the top of the box. The displacement of the yoke in relation to the top of the box may in this way be measured. A spirit-level, E, fixed to the box ensures accurate levelling of the yoke and completes the device.

To effect the desired centring, use is made of the frictional resistance, F, for each direction of rotation, the journal load, P, transmitted by the yoke being displaced by suitably turning the handwheels BB.

The two positions of equilibrium corresponding to frictional forces and loads F_1 P_1, and F_2 P_2 respectively are established by two successive readings of the comparator, and the spirit-level showing in each case the attainment by the yoke of the horizontal position. If the number of divisions read off the comparator in travelling from one extreme position to the other after changing the direction of rotation is $2e$, dead centre will be found by shifting the yoke in the opposite direction to its last displacement by an amount corresponding to e divisions.

NOTE : *Measurement of the coefficient of friction by the comparator method.*

Mr. Bastin, Manager of the Isothermos Laboratory, has shown that the use of the comparator employed for centring

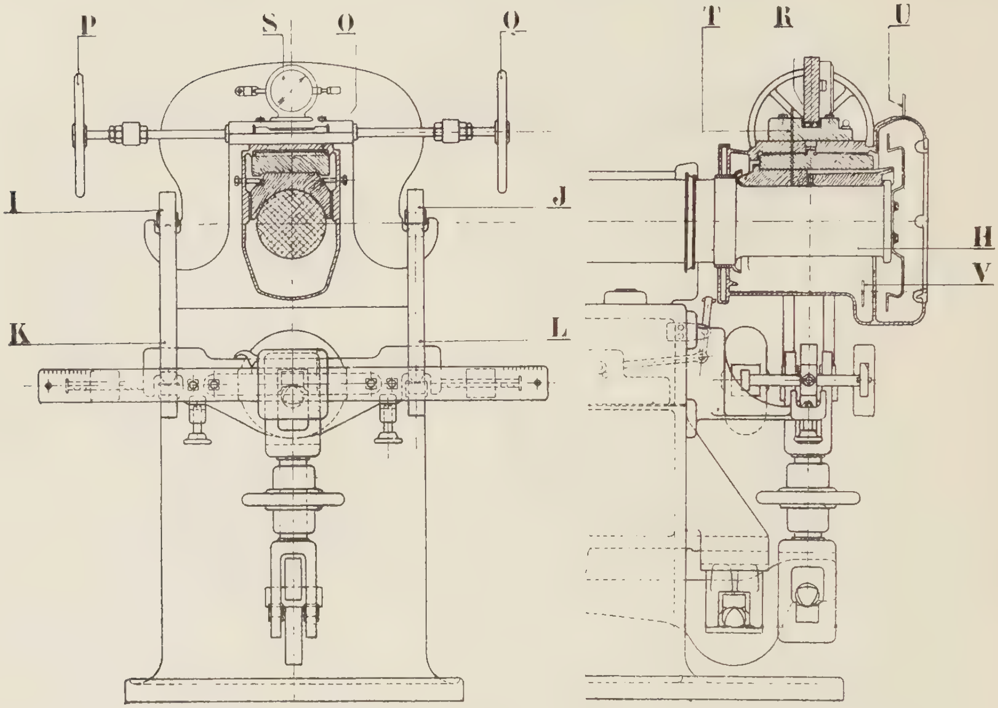


Fig. 9.

offers, if needed, a very simple method of calculating the value of the coefficient of friction, as is done with the machine at the Isothermos Laboratory, described later. The equation of equilibrium between the frictional force F and the load P is, as a matter of fact :

$$F \times r = P \times e; \text{ Now } F = f \times P$$

whence

$$f = \frac{F}{P} = \frac{F \times r}{P \times r} = \frac{P \times e}{P \times r} = \frac{e}{r}.$$

To determine the coefficient of friction by direct calculation it is therefore sufficient to divide by r (the radius of the journal) the number of divisions, e, corresponding to one half of the displacement of the yoke between the two positions for which the frictional resistance balances the load.

B. — **Isothermos Laboratory machine.**

The machine at the Isothermos Laboratory is constructed on the same principle as the Guillery-Haguenauer machine, but it has an advantage over the latter in that the journal is no longer placed between two bearings but is at the end of the shaft, which permits direct trial of any type of rolling-stock axlebox under actual service conditions.

This machine (fig. 9) comprises essentially an axle end supported in two bearings resting on a rigid steel frame. The axle is connected by a flexible coupling to the shaft of a 10-H.P.

variable-speed motor unit which is capable of speed regulation between 0 and 840 r.p.m. in either direction of rotation. This allows the attainment of journal speeds corresponding to the maximum speeds of express trains.

The load is applied to the overhanging journal H through a deformable parallelogram, I J K L, mounted on knife edges. It is provided by discs of known weight placed at the end of a lever which forms part of a system amplifying 40 times the actual weight of each disc which is 26 kgr. (57.3 lb.).

The displacement of the upper yoke of the parallelogram in relation to the top of the axlebox 0 is effected in the same way as in the Est Railway Company's machine, by means of large handwheels, P, Q, and is made easier by the insertion of a set of small rollers, R, between the seat of the yoke and its slide. This displacement, which involves movement of the line of action of the applied load, is read from the comparator, S, to 1/1 000 mm. and the traverse readings enable the coefficients to be measured in the same way as previously described.

At the same time as the coefficients of friction are ascertained, direct readings of suitably placed thermometers, T, U, V, may be taken to ascertain the temperatures successively attained

— by the bearing brass, in the immediate vicinity of the journal;

— by the top of the axlebox;

— in the oil well.

In addition, readings are taken of the pressure in the oil film (by means of a gauge on top of the bearing), the current consumption of the motor, and the speed of rotation of the journal.

The sensitivity of this machine is the same as that of the Est Railway Company's machine, coefficients of friction being measured to two units in the fifth decimal place.

C. — Woog machine.

The machine now to be described is due to Mr. Woog, whose many contri-

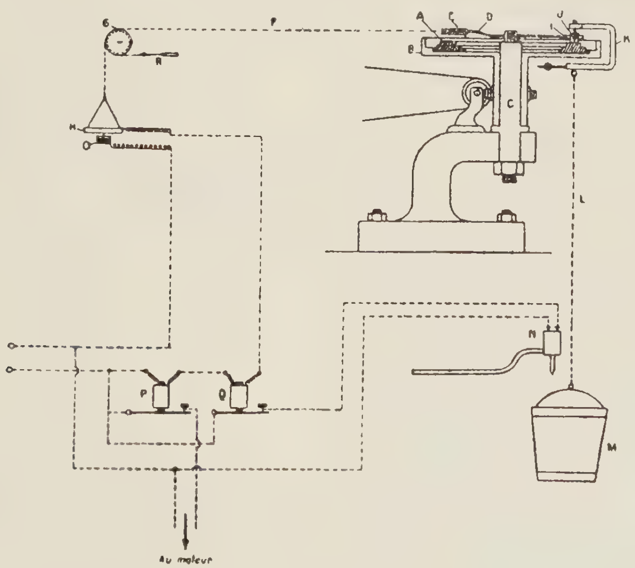


Fig. 10.

Note. — Au motor = to motor.

butions have been of major importance for the « science of lubrication ». It differs in principle from the apparatus previously described inasmuch as it is designed to *measure dynamic friction within the film*.

To this end the speed is kept low so that perfect lubrication cannot be established, viz : 0.1 m. (3 15/16") per minute and so that variations of oiliness may be clearly discerned.

The apparatus designed by Mr. Woog for this purpose is described in his work « Contribution to the study of lubrication ». It comprises a replaceable flat ring, A (fig. 10), made of case-hardened steel, screwed into a mild steel trough, B. The upper face of the ring, A, 150 mm. (6") in diameter and 25 mm. (1") wide, is carefully ground and polished. An electric motor, suitably geared down, causes trough and disc to rotate about the fixed spindle, C, at constant speed. At the top of the spindle, C, is a small cap beneath which a lever, D, is allowed to pivot freely. This lever broadens out at one end into a grooved quadrant, E, which guides a light chain, F, attached to D. This chain passes over a pulley, G, delicately mounted between centres, and ends at a scale pan, H. At the other end of D, and symmetrical with E, is a guide for centring the friction block, J. This block, which may be made of steel or of carbon, has its upper face provided with a conical recess which receives the steel point of a balanced stirrup, K, made of cast aluminium, the purpose of which is to apply, directly and without any mechanical articulation, a known pressure to the friction block. The load is applied to the stirrup through the chain, L. Gas jets heat the underside of the trough, B, and, consequently the ring, A.

The surfaces of the ring and the friction block are subjected to an especially detailed process of preparation worked out in the laboratory.

To carry out a test, a suitable weight, P, is placed in the pan, H, say 100 to 150 gr. (1 1/2 to 5 oz.), the motor is started and the friction block is placed upon the ring, which is covered by oil. The block is at first carried round, until it is home in a recess I, after which it slides on the ring. The stirrups, K, are placed in position. A receiver, M, fed by a water pipe at constant pressure, is hung from the chain, L. The weight of the receiver, M, is slowly and regularly increased and the load on the friction block J grows progressively. Eventually the lubricant no longer suffices to maintain free sliding of the block, and the friction increases until it balances the weight at H. The block is then carried round by the rotation of the ring, causing the lever D to swing and so raising the scale pan H. An electrical contact beneath the scale pan at O is broken at once and the stoppage of the motor and the water feed follows immediately. Any backward snatch of the lever D and the block at the moment of stopping, which would impair the condition of the rubbing surfaces, is prevented by a steel ratchet and pawl fitted to the pulley G.

The quotient of the weight P divided by the total weight M gives the value of the coefficient of friction.

Various refinements have been introduced into this method to permit reversal of rotation and to avoid certain causes of disturbance to which so delicate a test is exposed, particularly when the state of equilibrium is being approached.

Note. — The extreme care with which the friction surfaces must be prepared is illustrated by the following :

The steel friction blocks are first levelled on a wheel of rottenstone. They are then rendered plane by rubbing down on a polished glass surface in the presence of finely divided iron oxide and water. They are then washed with benzine and when dry are burnished on

polished glass smeared with the oil to be tested, until the steel has taken a mirror finish. The surfaces are then washed with the oil and wiped with filter paper which has soaked in the oil; a further oil wash is given and the friction block is finally placed upon the moving ring for the test proper.

D. — Vollet machine.

This machine, installed at the « Laboratoire National des Arts et Métiers », was devised by Mr. Vollet, in charge of the workshops of the test house, in accordance with the method outlined by Mr. Prévost, physicist attached to the same laboratory. The following description is taken from the Bulletin *Recherches et Inventions,* issued by the « Office National des Recherches Scientifiques, Bellevue » (February 1937).

(a) Principle of the machine. — The Vollet machine is a friction machine fitted with two tracks or rings, *a* and *b*, which derive a rotary movement from two concentric shafts, *c* and *p*.

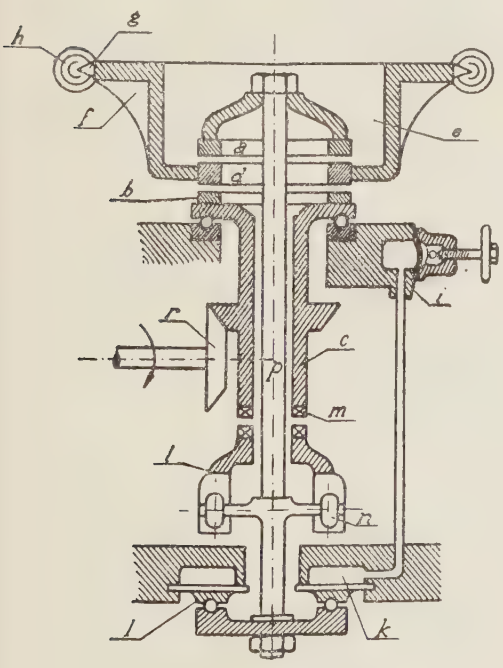


Fig. 11. — « Vollet » machine.

Between these two tracks lies a ring, *d*, which the frictional forces, acting upon its two faces, tend to drive round in their rotation. This ring is fixed in a cup, *e*, carrying two arms, *f*, which bear, through the stops, *g*, upon two manometric diaphragms, *h*. The ring is thus maintained in equilibrium by the following couples only :

— the frictional torque on the upper face;

— the frictional torque on the lower face, and the reacting couple of the diaphragms.

The adjustable load on the two faces of this ring is applied in the following manner :

The hydraulic press, *i* exerts pressure at K upon a diaphragm which, through a ball thrust bearing, *l*, produces a vertical downward thrust upon the shaft which drives the upper track. This thrust is transmitted through the ring to the lower track which has, in addition, to carry the weight of the cup and of the intermediate ring.

The rotary movement is imparted to the shaft, *c*, by the gears, *r*. The shaft, *p*, derives its motion from the shaft, *c*, through the following intermediate members : a clutch, *m*, two stops, *t*, and two rollers, *n*. This arrangement permits of the axial displacement made necessary by the thrust of the loading diaphragm upon this shaft.

(b) Description of the machine. — The machine at present in service in the testing laboratory, and shown in the accompanying illustration has a total height of 1.60 m. (5' 3").

The principal mechanical parts are cased in. A clutch lever throws into mesh either the shaft carrying the lower track, or the two shafts together turning at the same speed. Flat circular tracks

fixed at the upper ends of the shafts may be made of the same metal or, for comparative wearing tests, of different metals. Both tracks (*a* and *b*) are machined to internal and external diameters of 60 mm. (2 3/8") and 80 mm. (3 5/32") respectively.

Between these two tracks comes a ring, *d*, having the same inside and outside diameters. Its flat faces are grooved to admit the lubricant.

A small handwheel on the top of the machine actuates the primary piston of the hydraulic press which forces an aqueous solution of glycerine into the chamber, *k*, above the diaphragm.

The lubricant is fed drop by drop to the intermediate ring.

An electric heater is fitted, capable of raising the temperature of the lubricant and of the ring to 200° C. (392° F.).

When required, a double jacket placed around the intermediate ring is used to maintain a constant temperature or to produce very low temperatures.

The machine is fitted with the following instruments :

1. A thermometer which is in contact with the ring and submerged in the oil being fed to it.

2. A revolution counter and a tachometer to ascertain the rotational speed of the tracks.

3. A pressure gauge graduated from 0 to 25 kgr./cm² (356 lb./sq. in.) which records the pressure of the hydraulic press upon the tracks.

4. A pressure gauge graduated from 0 to 500 grammes, recording the force exerted upon the manometric diaphragms by the arms which move with the ring. This gauge is calibrated to give readings expressed as a couple, by means of weights hung from the end of a lever 0.250 m. (9 7/8") in length.

(c) Operation of the machine. — If r_2 and r_1 are the external and internal diameters of the tracks;

k, the coefficient of friction;

p, the pressure per unit area upon the tracks;

then the frictional torque exerted by elements at radius *r* may be represented by the equation

$$dM = k \cdot 2 \cdot \pi \cdot r \cdot dr \cdot p \cdot r \cdot$$

The total couple on the tracks will therefore be

$$M = \int_{r_1}^{r_2} k \cdot 2 \cdot \pi \cdot r \cdot dr \cdot p \cdot r = 2\pi kp \frac{1}{3} (r_2^3 - r_1^3). \quad . \quad . \quad . \quad . \quad . \quad (a)$$

If P is the total pressure exerted upon each track, and p_0 the weight of the system containing the intermediate ring, the unit pressures will be

$$p_1 = \frac{P}{\pi (r_2^2 - r_1^2)} \text{ (upper track)}$$

$$p_2 = \frac{P + p_0}{\pi (r_2^2 - r_1^2)} \text{ (lower track)}$$

The expression *(a)* then becomes

$$M = \frac{2\pi k}{3} (r_2^3 - r_1^3) \left(\frac{P + p_0}{\pi (r_2^2 - r_1^2)} + \frac{P}{\pi (r_2^2 - r_1^2)} \right) = \frac{2}{3} k \frac{r_2^3 - r_1^3}{r_2^2 - r_1^2} (2P + p_0).$$

If we call :

l the length of the lever arm represented by the distance between the axis of the machine and the diaphragms, *g*, and φ the thrust exerted on the diaphragms, then

$$M = 2 \varphi l.$$

This couple is balanced by a tare in the form of a weight ω acting at a leverage of 250 mm. (9 7/8 in.)

$$M \text{ also} = \omega \times 0.250.$$

whence

$$M = \omega \times 0.250 = \frac{2k}{3}\frac{r_2^3 - r_1^3}{r_2^2 - r_1^2}(2P + p_0)$$

and

$$k = \left[\frac{3}{2} \times 0.250 \times \frac{r_2^2 - r_1^2}{r_2^3 - r_1^3}\right] \times \frac{1}{2P + p_0} \times \omega.$$

The dimensions of the tracks being known, the expression in brackets is a constant and

$$k = \frac{A\,\omega}{2P + p_0}.$$

It is therefore sufficient to choose different values for P at each speed, and to find φ for each case. In this way any desired number of points are quickly obtained, lying on a curve which shows the coefficient of friction at any given speed in terms of the pressure.

Note. — The Vollet machine measures coefficients of friction, and also records the three experimental variables : temperature, speed and pressure within the following limits :

— temperature — 20° to 200° C. (— 4 to 392° F.);

— speed 0 to 1 700 r.p.m. (corresponding to a range of linear speed between 0 and 6 m. (19.7') per sec.;

— pressure between 0.3 and 100 kgr./cm² (4.3 and 1 422 lb./sq. in.).

The accuracy of the machine depends on the one hand, upon the accuracy of the gauges which measure the couples and the pressure, and on the other hand upon the stability of the frictional torque.

The relative error of the measurements of the coefficients of friction varies between 4 and 8 parts per thousand.

E. — Machine at the Research Station of the Reichsbahn.

This machine was built by the German Railways after the War, with the object of studying at first hand the causes of the then very numerous cases of hot axleboxes. It is also designed to determine, in terms of the speed and load, the coefficients of friction of axle journals rotating in the corresponding axleboxes.

The machine has a certain similarity to those of the Est Railway Company and the Isothermos Laboratory. Its essential components are a parallelogram

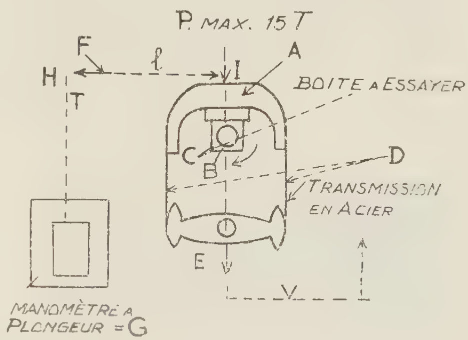


Fig. 12.

Explanation of French terms:

P. max. 15 T. = maximum load 15 metric tons. — Boîte à essayer — axlebox under test. — Transmission en acier = flexible steel connection. — Manomètre à plongeur. = plunger pressure gauge.

system (fig. 12) in which the upper yoke, A, swings about a steel shaft, B, carrying a journal which, with its bearing, is enclosed in an axlebox, C. This yoke is connected by two flexible steel bands to a second swinging yoke, E. A variable downward pressure upon the member, E, is applied by a piston and

a system of levers and registered by a recording gauge.

The attachment for measuring co-efficients of friction consists of an extension, F, of the upper yoke, linked with a piston dynamometer, G.

The frictional torque is measured, on the one hand, by the product

$$P \times f \times r,$$

P being the load, in kgr., transmitted to the journal;

f being the coefficient of friction, and

r being the radius of the journal in metres.

The opposing couple, on the other hand, is given by the product $T \times l$, wherein T is the force, in kgr., measured by the dynamometer and exerted at the end of the lever arm, H I, of length l.

From the equation $P \times f \times r = T \times l$ is deduced f, the value of the coefficient of friction for a given load and speed.

Note. — The variation of the coefficient of friction with the heating of the bearing is followed by means of a thermometer the bulb of which is located within the bearing.

As in the case of the Isothermos machine, this apparatus may be used to determine the coefficients of friction for different types of axlebox, fitted with brasses or with roller bearings.

Conclusion.

The various tests carried out with machines of the types described have made it possible to express the laws governing the coefficient of friction in the presence of an oil film, in terms of the speeds and loads. These same machines enable characteristic curves to be drawn, for lubricants and antifriction alloys, such as define the best conditions of service, and indicate the directions in which still further improvement may be sought, as the author has outlined in a previous survey (See *Chemins de Fer et Tramways* for January, 1938).

[625. 215]

Tests about the behaviour of railway vehicles on the track (*),

by Ad.-M. HUG,

Consulting Engineer, M.I. Mech. E., Thalwil-Zurich (Switzerland).

The mechanical conditions under which road and railway vehicles move along their path vary widely owing to their very diverse and more or less arbitrary design. If left to itself, a cylinder rolling on a horizontal plane will take a course perpendicular to its centre line. The same phenomenon will occur during the motion of a pair of railway wheels or road motor car wheels. The latter vehicle can be easily steered in any given direction and, owing to its small supporting base (wheel base), it offers little resistance to a change in direction; as is well known, it runs steadily in this respect.

As a general rule, railway wheels are not steered : two or three pairs with their axles are housed in a common underframe, and owing to their great supporting length (also to the track gauge), they offer an appreciable resistance to any deviation from their initial path : forced guiding by the wheel flanges occurs.

Figure 1 represents a section of a worn rail and of a wheel tyre; the wear of the originally symmetrical rail head, as well as of the tyre — semi-circular when new — is clearly shown. Such wear is due to the fact that, for any non-tangential position of the wheel in relation to the rail, the contact between the two bearing faces has taken place, not along a continuous line, but at two points shown in figure 1 as A = supporting point, and a = bearing point of the wheel flange, respectively.

The instantaneous axis of rotation resulting from the motion of the wheel passes neither through A, nor through a. These points of the wheel must consequently glide under high pressures and produce friction with resulting wear of the two parts in contact.

In practice, the consequence thereof is a restriction of the permissible wheel loads, of the distance between axle centres and of the maximum radius of curves, the use of bogies becoming generally necessary.

The scientifical investigation of these questions clearly shows that, by automatic control of the steering of wheels, such losses of power and constituent material can be avoided, and that the

Fig. 1. — Section through worn rail and tyre, taken from one of the cars described, before modification.

(*) This article is reproduced from *The Railway Gazette*, June 10, 1938, but has been slightly modified by the Author, several illustrations being also added.

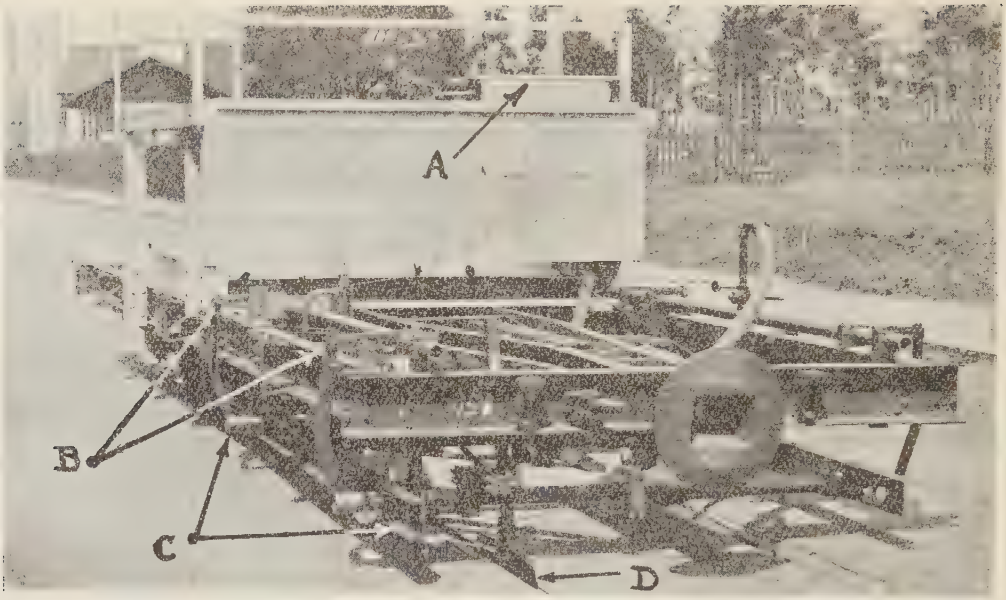


Fig. 2. — Experimental truck with the Amsler measuring equipment.

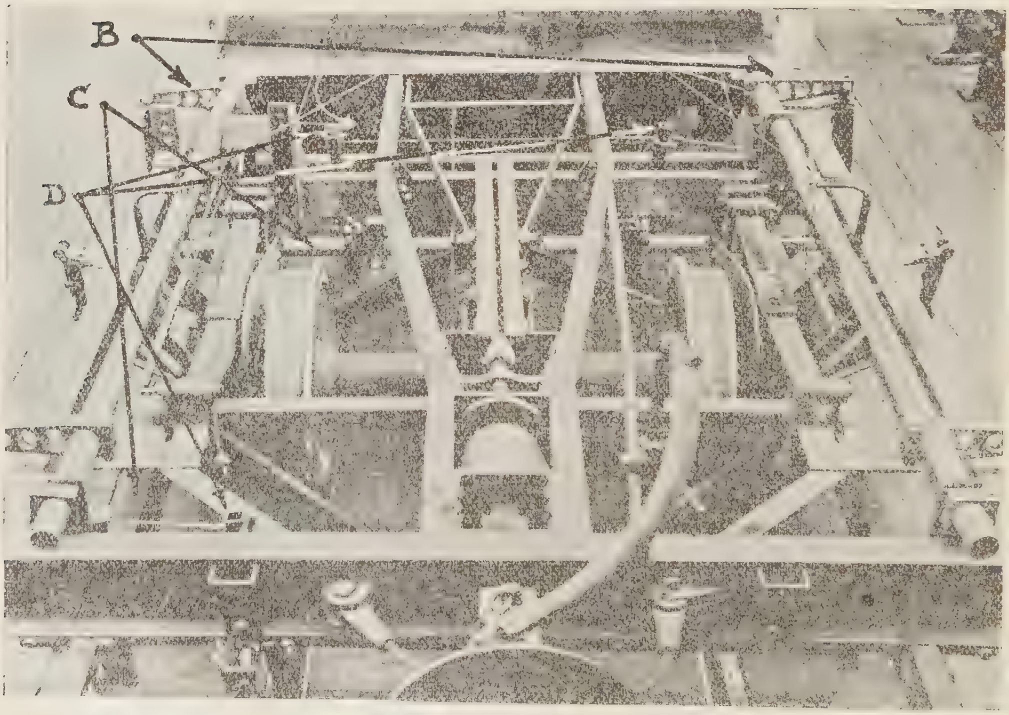


Fig. 3. — Underframe of vehicle, fig. 2, showing arrangement of transmission cables.

Legend of figures 2 and 3:

A = Recording apparatus (fig. 5).
B = Transmission mechanism with parallel motion through rods and cranks.
C = Measuring frame.
D = Feelers.

behaviour of vehicles on the track can be made much more independent of irregularities in the running surface. Attempts to solve the problem in this way have been made ever since the early days of the development of railways.

The support of the Swiss Foundation for Public Economy, and of various private Railway Companies, has made it possible to carry out systematic tests with railway trucks of different types (*), the apparatus for which was designed and constructed by Alfred J. Amsler & Company, of Schaffhouse (Switzerland).

The problem was to determine the relative positions of the wheel, the rail and the body of the carriage when passing over irregularities in the track. This had been attempted several years earlier by taking cinematographic pictures, but no satisfactory results had been obtained, owing to the smallness of the angles and displacements which had to be considered and the shortness of the intervals of time of the exposures.

Figs. 2, 3 and 4 represent the new measuring device in principle and as constructed. The main part is a hori-

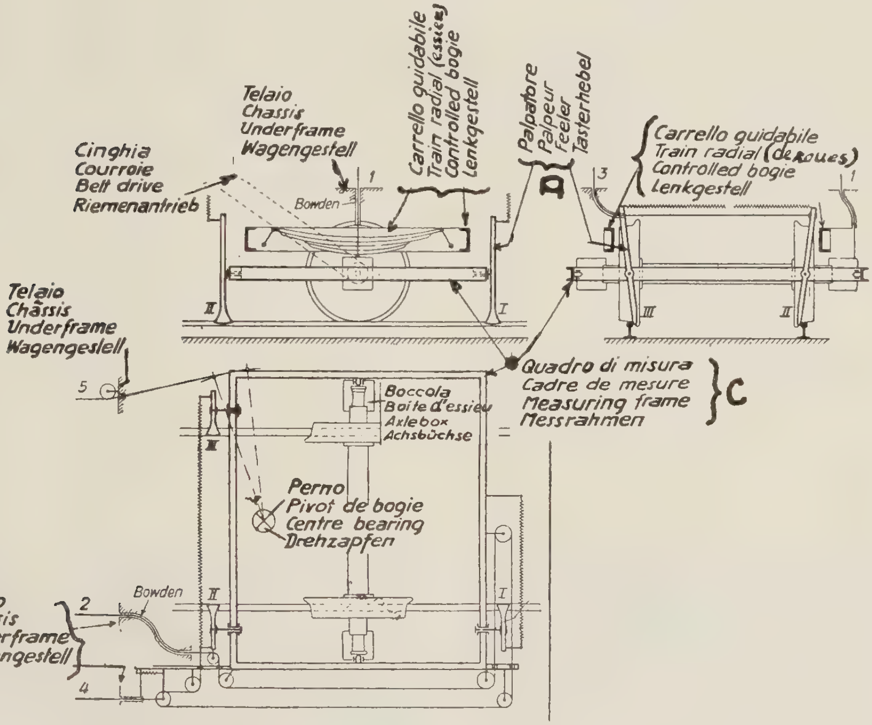


Fig. 4. — Layout diagram of the Amsler measuring equipment, showing the arrangement of the transmission cables, the centring devices and recording method (compare with fig. 5).

(*) The full reports of these researches have been published by R. Liechty and are entitled « Messungen über die Spurführung bogenläufiger Eisenbahnfahrzeuge », Berne, 1936.

zontal frame of rolled-steel sections, strengthened by means of diagonal timber bracing, which entirely surrounds a pair of wheels. This frame is suspended on pivots placed in the heads of the axle trunnions and is kept parallel to the rails by means of a system of rods and parallel cranks. With the exception of this parallel guiding it is entirely free to describe with the axle — with which it forms a unit — any movement relatively to the carriage body. Three feelers (I, II and III, fig. 4) pivoted to this frame are pressed by springs against the gauge faces of the rails and serve to determine the relative movements of the frame, i.e., of the wheels, relatively to the rails. The location and support of the measuring frame ensures the correct guidance of the feelers on the track and fixed positions of their pivoting axes relatively to the axle.

As will be seen from figure 4, a movement is imparted to wire 2 inversely as feeler I, and directly as feeler II, move relatively to the frame, and the wire therefore registers mechanically the absolute difference of the angular movements of the two feelers, which difference is proportional to the trigonometric tangent of the angle between the plane of the wheel and the rail. The difference thus registered is transmitted directly to the recording apparatus by means of a Bowden wire, the other end of the tube of which butts against the frame of the vehicle under test and thus eliminates the parasitic influence of the relative movement between it and the feelers.

The Bowden cable 3, actuated by the movements of the feelers II and III mounted opposite to each other, measures the width of gauge of the rails under the vehicle. A Bowden wire 4 is attached to a pulley over which runs a cable connected to the feelers I and II, this pulley being carried from the frame by a long lever. This system records the average of the angular displacements of the two feelers in contact with the same rail relatively to the frame, in other words, the distance between the plane of the wheels and the rail in question.

Fig. 5 — Amsler recording device mounted on the trial truck (A in fig. 2).

On curves it is necessary to deduct from this record an amount to allow for the deflection of the rail between the two feelers. This slight correction presupposes, of course, that the curvature of the rail at this spot is known.

Other cables serve to record the relative movements between the measuring axle and the vehicle underframe. Cable 5, for instance, indicates the angular displacement of the axle with regard to the underframe, whilst cables such as 1 record the deflection of the laminated springs relatively to the bogie as a measurements of the individual load on the wheels. Between the bogie and underframe cables 1 pass through Bowden tubes. In consequence of the internal friction of the leaf springs, this method includes certain errors, but in spite of this the method was adopted on account of its simplicity and because it affords indications of the major increases and decreases of load.

For all cable transmissions 2-mm. (about 5/64 in.) torsion-free steel cables were used, and all the pulleys rotate on ball bearings and are enclosed in dust-proof housings. The ends of the metal hose or sheath of the Bowden systems are soldered to the respective pulley housings; figure 3 shows how the cables are led. The layout had to be arranged with great care so as to prevent as far as possible all friction, and in such a way that the initial tension in all the cable lines as well as in the counter-springs was not too high.

All the measured values are recorded on a paper strip 600 mm. (23 5/8 in.) wide, moved forward as a function of the distance travelled by means of a flexible shaft driven by the axle. The recording apparatus is shown on a larger scale in figure 5. To mark special sections travelled over or peculiarities of the track, the recorder is provided with a hand-operated trigger stylo. In order that the apparatus may be applied to different vehicles, the measuring fra-

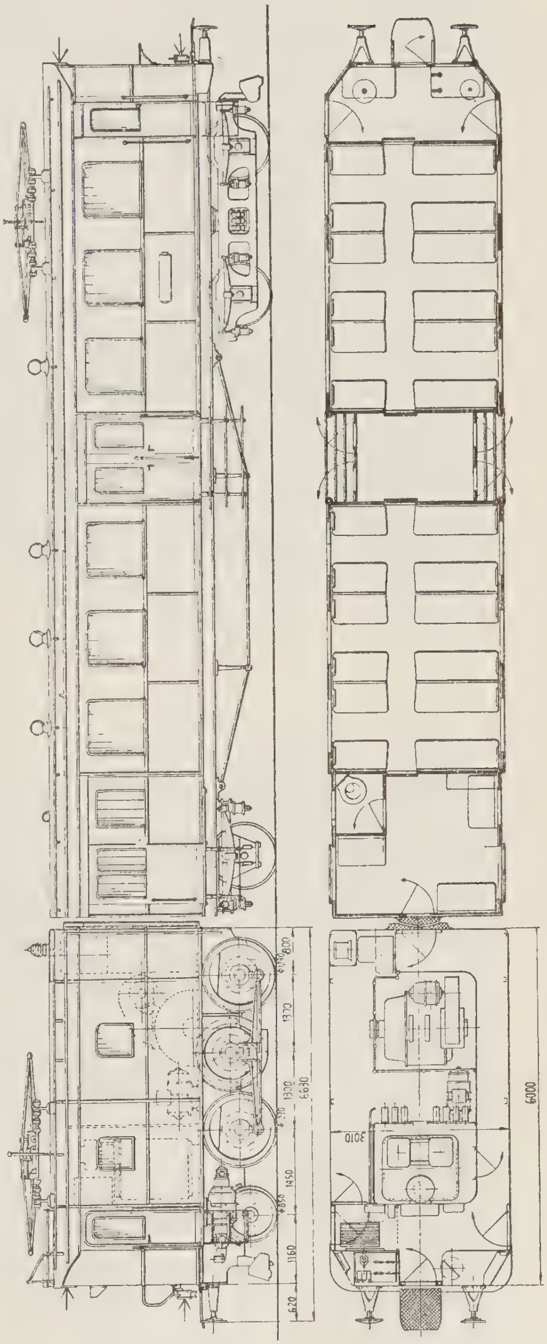


Fig. 6. — Elevation and plan of class CFe 2/6 motor-and-coach units Nos. 784 and 785. Berne-Loetschberg-Simplon Railway.

me and its guides are made extensible both longitudinally and transversely by rods and cranks, and the feelers are also adjustable. This measuring arrangement has amply fulfilled expectations and has enabled extensive experimental results to be compiled.

One of the most instructive experiments was obtained on electric railcar CFe 2/6 No. 785 of the Berne-Loetschberg-Simplon Railway. This coach consists of a motor unit with 1B wheel arrangement (it is half of a standard electric locomotive) and a carriage unit with a floating intermediate carrying axle and a four-wheel bogie at the rear (figs. 6 and 7). The two units are so connected that on curves the motor unit takes up compulsorily the direction of the coach. The floating intermediate axle, which is close to the motor unit, originally had a lateral play of 2 × 50 mm. (2 × 2 in.) for the 10.750 m. (35 ft. 3 1/4 in.) wheelbase. This car, before the investigations, had been in service between tyre renewals, i. e., up to a wear of 8 mm. (5/16 in.) of the tyre diameter, some 30 000 km. (19 000 miles) between Berne and Schwarzenburg which has many 180-m. (9 chains) curves. The fixing up of the measuring arrangement to the intermediate carrying axle of this electric railcar is shown in figure 8.

The diagrams in figures 9 and 10 show the behaviour on curves of the floating axle as originally built, and figure 12 as subsequently altered, *(a)* when the motor unit is leading and *(b)* when it is trailing (pushing). As originally built, in *(c)* the axle leads at the outer rail with an angularity of 1 deg. 30 min., and in *(b)* it leads at the inner rail with an angularity of 1 deg. 55 min. The angular displacement occurs in jerks at the beginning and end of each curve, these jerks being communicated through the lateral controlling springs to the underframe and body.

The points of contact between wheel and rail were determined graphically from the known profiles of rail and tyre and the measured angles of incidence or striking of the flanges. Chalk marks were applied to the flanges and the rails for subsequent verification, and the paths travelled by the wheels during a complete revolution were measured so that the magnitude and direction of the slipping which took place at the points of contact on the rails were known. The results obtained are shown in the following table :

Trial.	Outer rail of curve.		Inner rail of curve.	
	Tyre diameter.	Distance travelled/π.	Tyre diameter.	Distance travelled/π.
Fig. 9	1 017.0 mm.	1 020.0 mm.	1 013.9 mm.	1 010.8 mm.
Fig. 10	1 013.0 mm.	1 021.8 mm.	1 017.9 mm.	1 013.6 mm.
Fig. 12	1 009.0 mm.	1 010.5 mm.	1 006.0 mm.	1 002.6 mm.

Trial.	Diameter at bearing point of flange.	Vertical distance between bearing points of tyre on rail table and of flange against side of rail-head.
Fig. 9	1 040.0 mm.	10.65 mm.
Fig. 10	1 044.0 mm.	11.80 mm.
Fig. 12	—	—

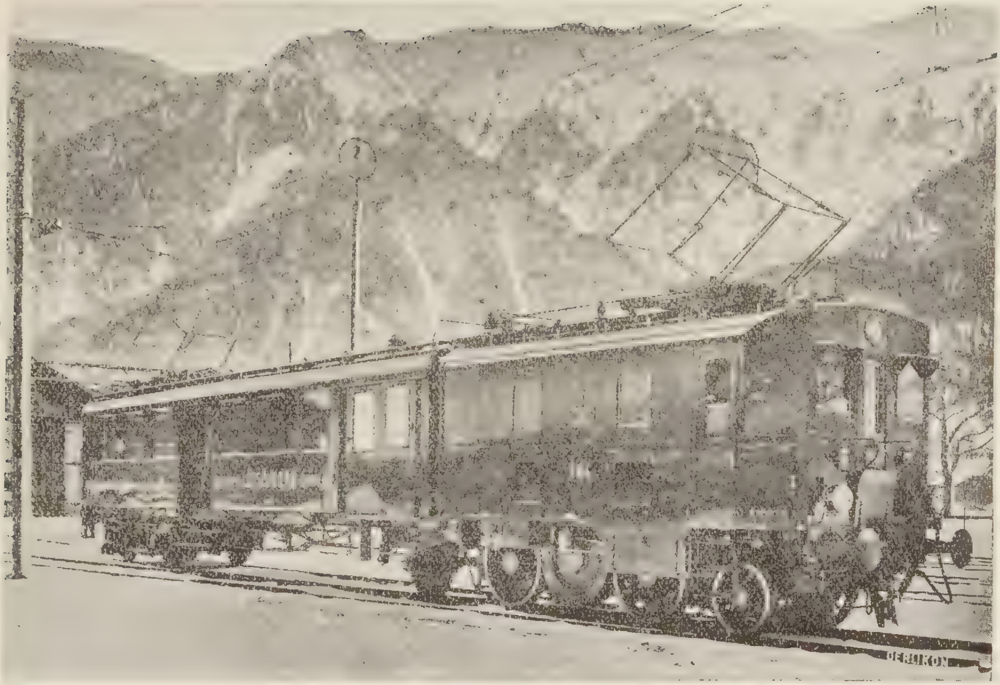


Fig. 7. — Electric motor coach No. 784 (see fig. 6), B-1—2 type, of the Berne-Loetschberg Simplon Ry., converted to include a single radial axle of the Liechty system : the rear carrying axle of the motor bogie.

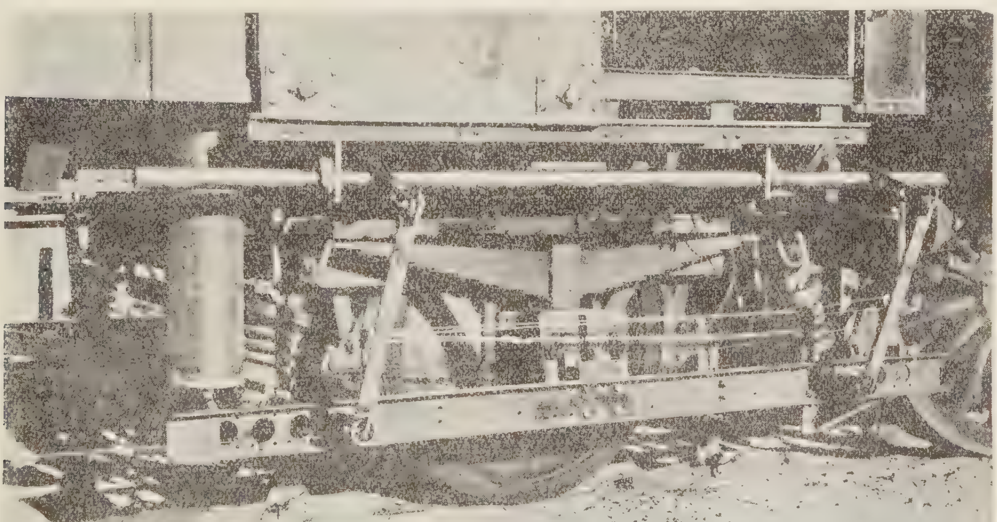


Fig. 8. — Amsler measuring device mounted on the radial axle mentioned in fig. 6 (4th axle from the right).

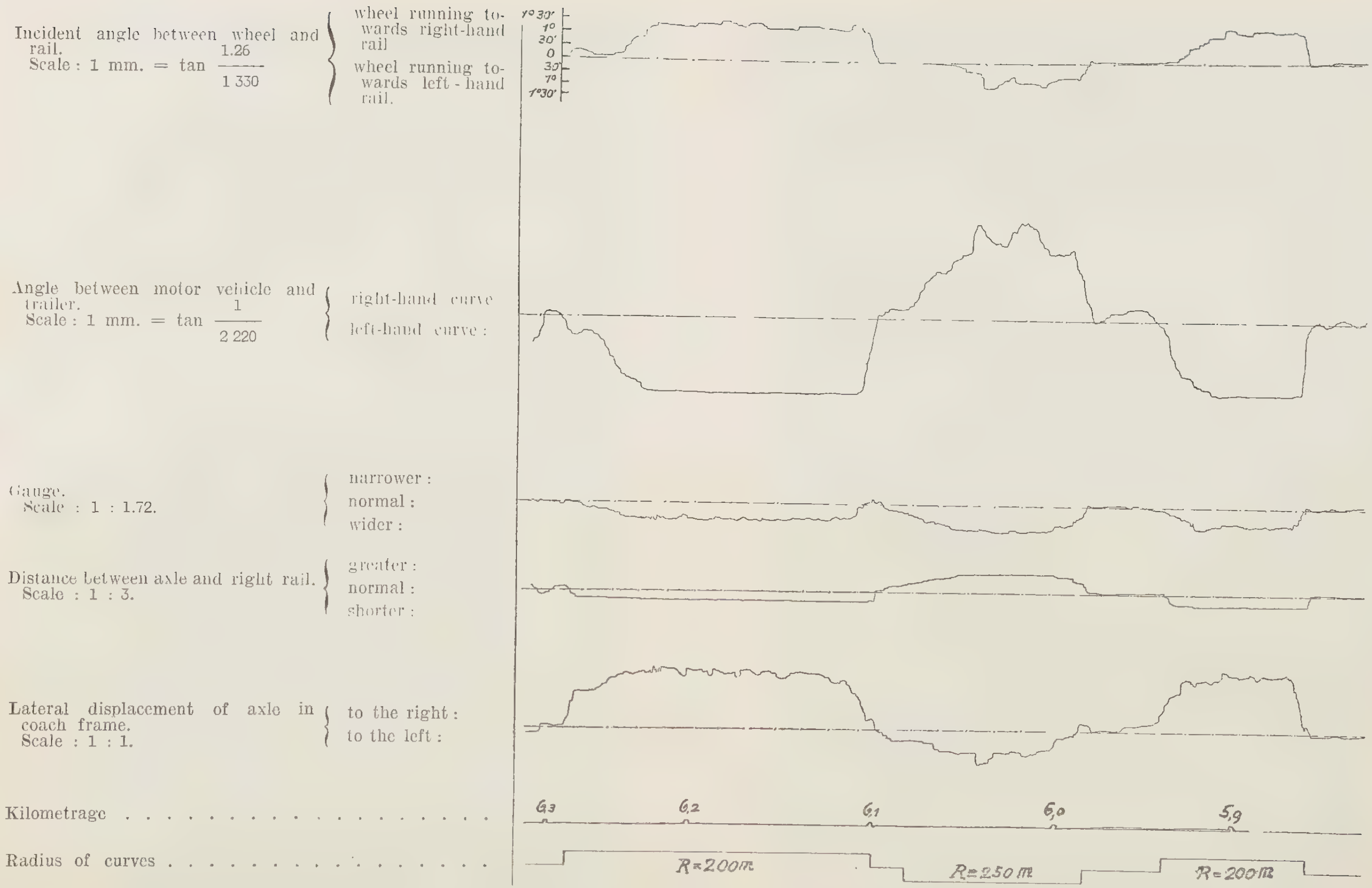


Fig. 9. — Diagrams taken on the Burgholz-Wimmis (Simmenthal) run; coach part trailing; November 2, 1934; motor coach BLS, No. 785.

Note. — The scales shown on all these diagrams (figs. 9, 10, 12, 14 and 15) are valid for the original diagrams only, the latter being much reduced in size for reproduction purposes.

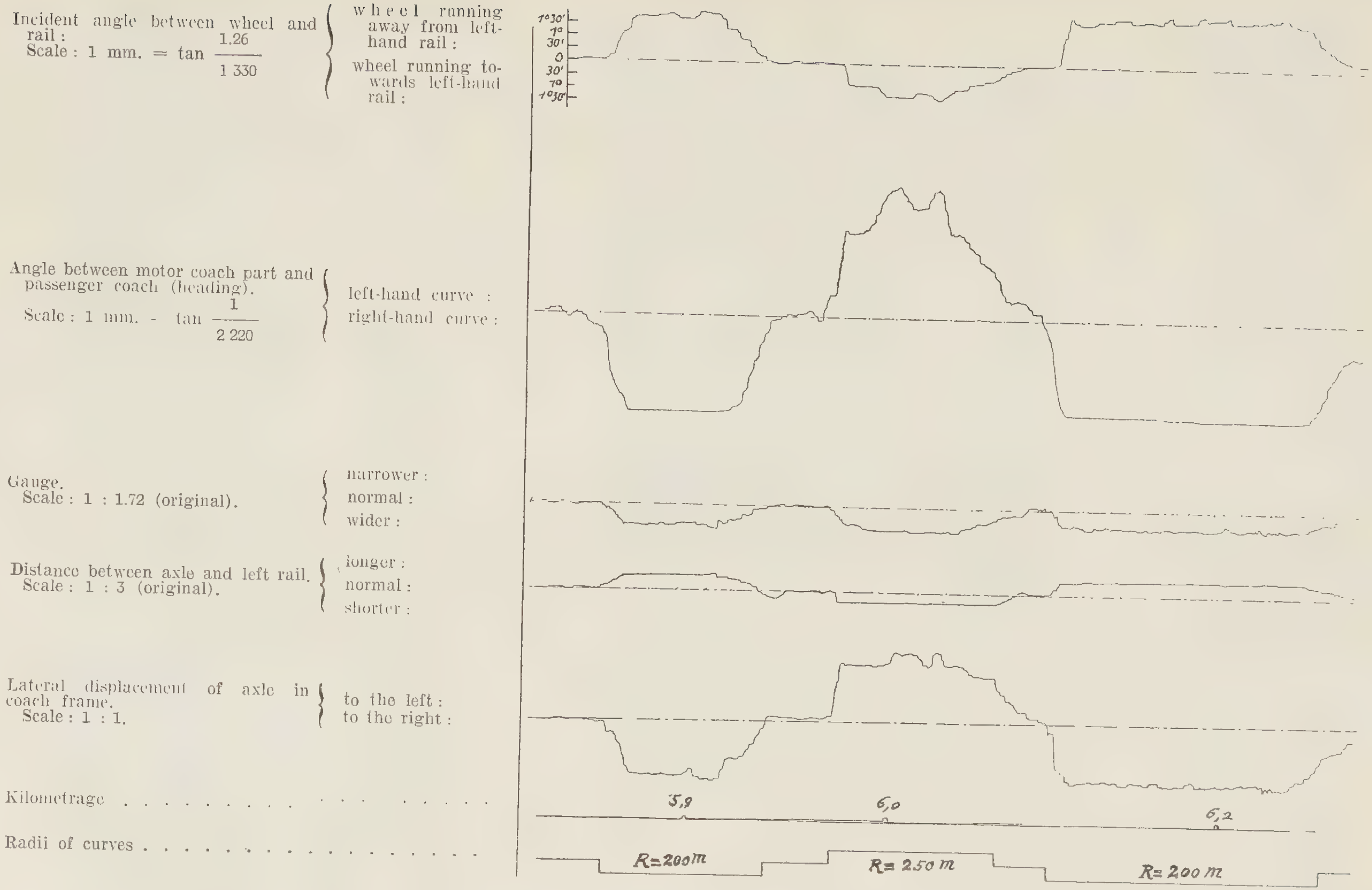
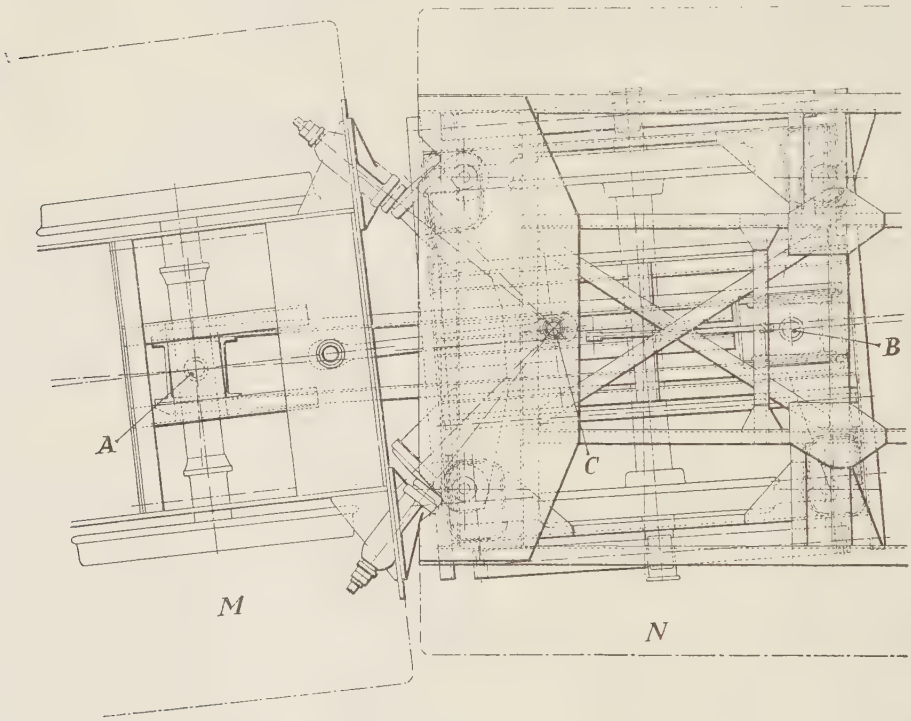


Fig. 10. — Diagrams taken on Wimmis-Burgholz run, passenger coach part heading; November 2. 1934; motor coach BLS, No. 785 (see *Note*, fig. 9.)

The specific resistance of a vehicle on a curve depends upon the frictional energy expended at the points of contact between wheels and rails, and this is determined by the loads on the contacts and the velocities of slip. The data obtained in the course of the present investigations, applied to Professor Heumann's conditions for static equilibrium (*), showed that, as originally built, the normal pressure at the flange, on a 188-m. (617-ft.) radius curve, and with a flange inclination of 70 deg., is 40 per cent. of the wheel load. The vertical component is about 22 per cent., i.e., this proportion of the wheel load is supported at the point of contact of the flange. With a coefficient of friction of 0.2, the « curve resistance » is 7.54 kgr. per t. (16.9 lb. per Engl. ton) for the case represented by figure 9, and 10.85 kgr. per t. (24.3 lb. per Engl. ton) for that represented by figure 10. From



A = Pivoting point of the single radial axle bogie; this point is located on the centre line of the motor unit part of the vehicle;
B = Point of connection between the bogie with single radial axle and the carriage part, by means of a guiding pin, moving longitudinally in the frame of this bogie;
C = Original connection, retained between the two units (motor and carriage) composing the vehicle;
M = Motor unit;
N = Carriage unit (coach).

Fig. 11. — Plan view of radial axle
(modification to electric motor coach No. 784 BLS of figs. 7 and 8).

(*) See *Organ für die Fortschritte des Eisenbahnwesens*, December, 1934.

this it will be seen that the « inside incidence » (of the flanges on the rails) considerably increases the resistance on curves. The energy expended at the flanges amounts to about 40 per cent. of the total resistance which has to be overcome on curves, and is of crucial importance as regards the life of tyres and outer rails.

In order to reduce the heavy wear on the flanges observed in practice, it was decided to apply radial steering to the axle, thus bringing the point of contact of the flange into the meridian plane of the wheel, reducing longitudinal slipping and eliminating transverse slipping. On the basis of the angles between wheel and rail, and between engine and carriage units of the railcar as determined during the trials, the Liechty controlled single-axle bogie has been designed (*). Figure 11 shows this type of controlled radial bogie as constructed for these railcars. It pivots at *A* on the centre line of the motor unit and is jointed at *B* to the carriage unit by means of a directing pivot longitudinally displaceable in the radial truck. The original articulated connection between the two units is retained at *C*. The control of the radial axle takes place as a function of the angle established in cur-

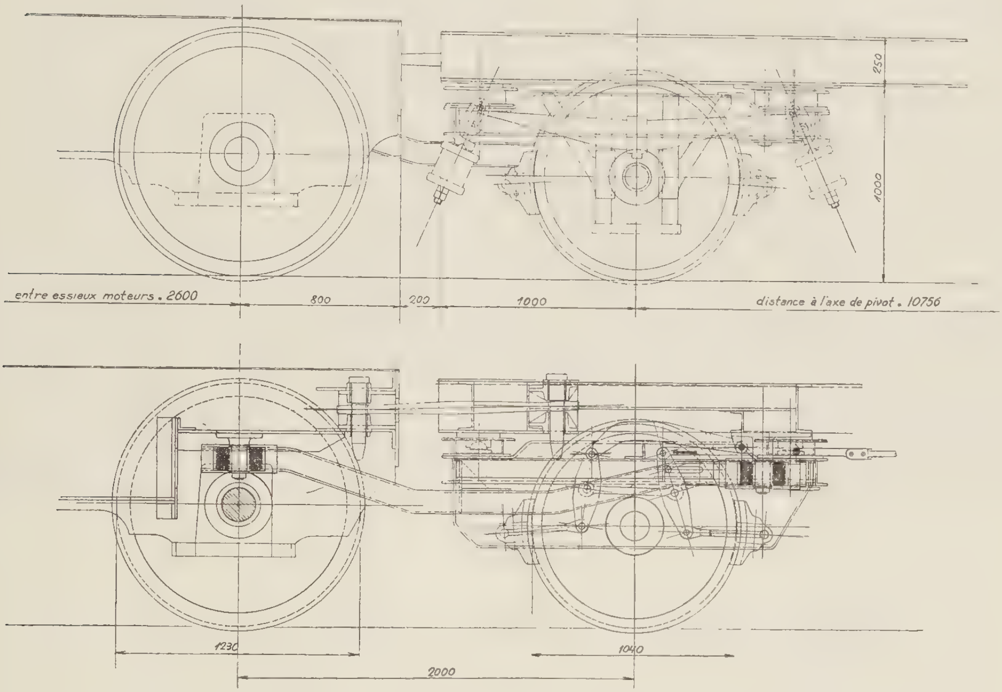


Fig. 11*b*. — Elevation and vertical cross section of the two axles (driving and carrying) near the articulation (see figs. 6, 7, 8 and 11).

(*) The Liechty system of steerable axles was described in *The Railway Engineer* of October, 1931, pp. 375-377.

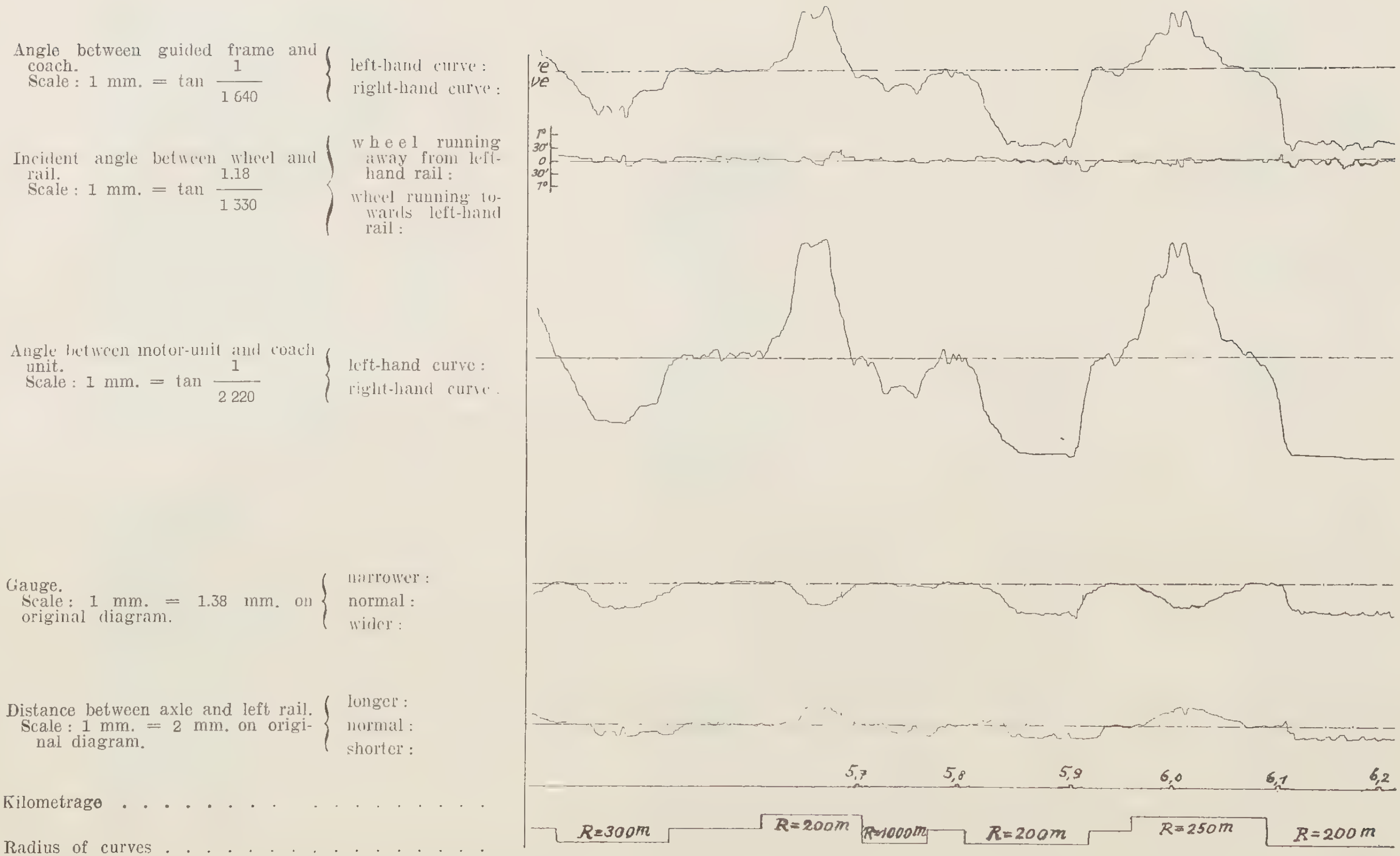


Fig. 12. — Diagrams taken on the Wimmis-Burgholz (Simmenthal) run; carriage unit heading; November 24, 1934; motor coach BLS No. 785, modified (compare in particular the second curve in this diagram with that on top of fig. 10).
(See *Note*, fig. 9.)

ves between the two units, which angle is proportional to the radius of the curve. In view of the long wheelbase of the two parts of the railcar exact guiding of the controlled axle is ensured on curves as well as on the straight.

The measuring equipment described is also suitable for the observation of varying conditions on curves, which conditions cannot be calculated by the methods hitherto available. The Amsler equipment was also fitted to an old Klo-

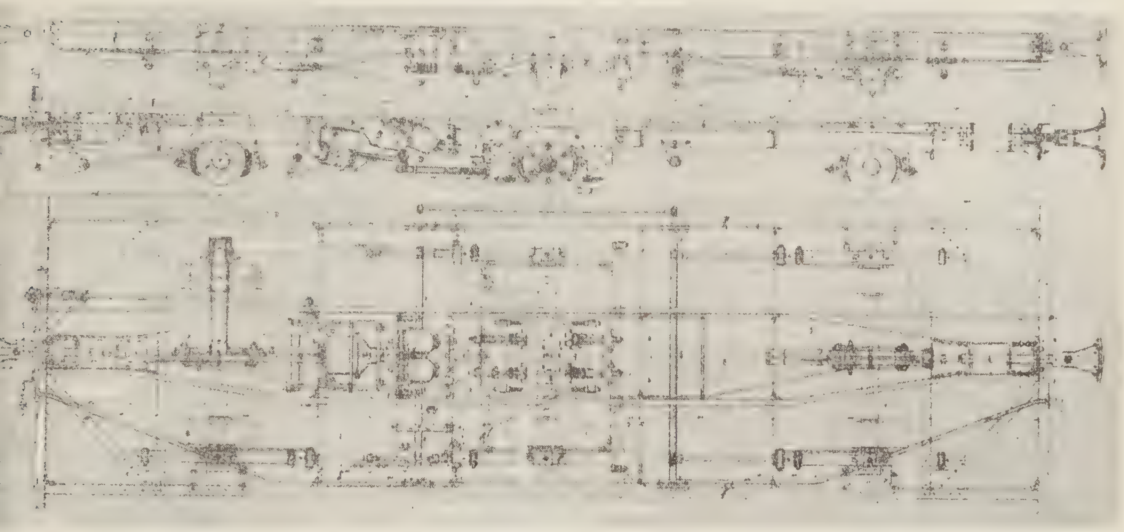


Fig. 13. — View of underframe of three-axle vehicle for rack and adhesion, Klose system, of the St. Gallen-Gais-Appenzell Railway (Switzerland), as designed in 1885.

By means of this very simple modification, a radial orientation of the controlled single-axle bogie is obtained, for all the curves, as indicated in figure 12 and the table above. The remaining friction of the flanges, which is very much reduced, serves to guide the vehicle, and what remains of the resistance in curves can be attributed to insufficient coning of the tyres. The resistance on curves has thus been reduced to 0.74 kgr. per t. (1.66 lb. per Engl. ton), i.e. to but 7 to 10 % of the previous value. After a further distance of 110 000 km. (69 000 miles) covered by the altered coach on the same section of the line and under the same conditions, the flange wear was but 1 mm., i.e., only about 7 % of the former wear.

se-type six-wheel vehicle (see fig. 2) in use on the narrow-gauge St. Gall-Appenzell Railway. In this design, the end axles are steered on curves by the laterally displaceable centre axle.

The graph obtained (fig. 14) showed that the angle between wheel and rail averaged zero for the complete curve, but its instantaneous values fluctuated widely and alternated in sign. The leading wheel was shown to hunt, and the movement of the controlled axle relatively to the underframe oscillated accordingly. The records obtained for the front and rear axles showed opposed hunting of the two axles. The reason for this is as follows :

On entering a curve, there is at first no steering of the axles; the leading

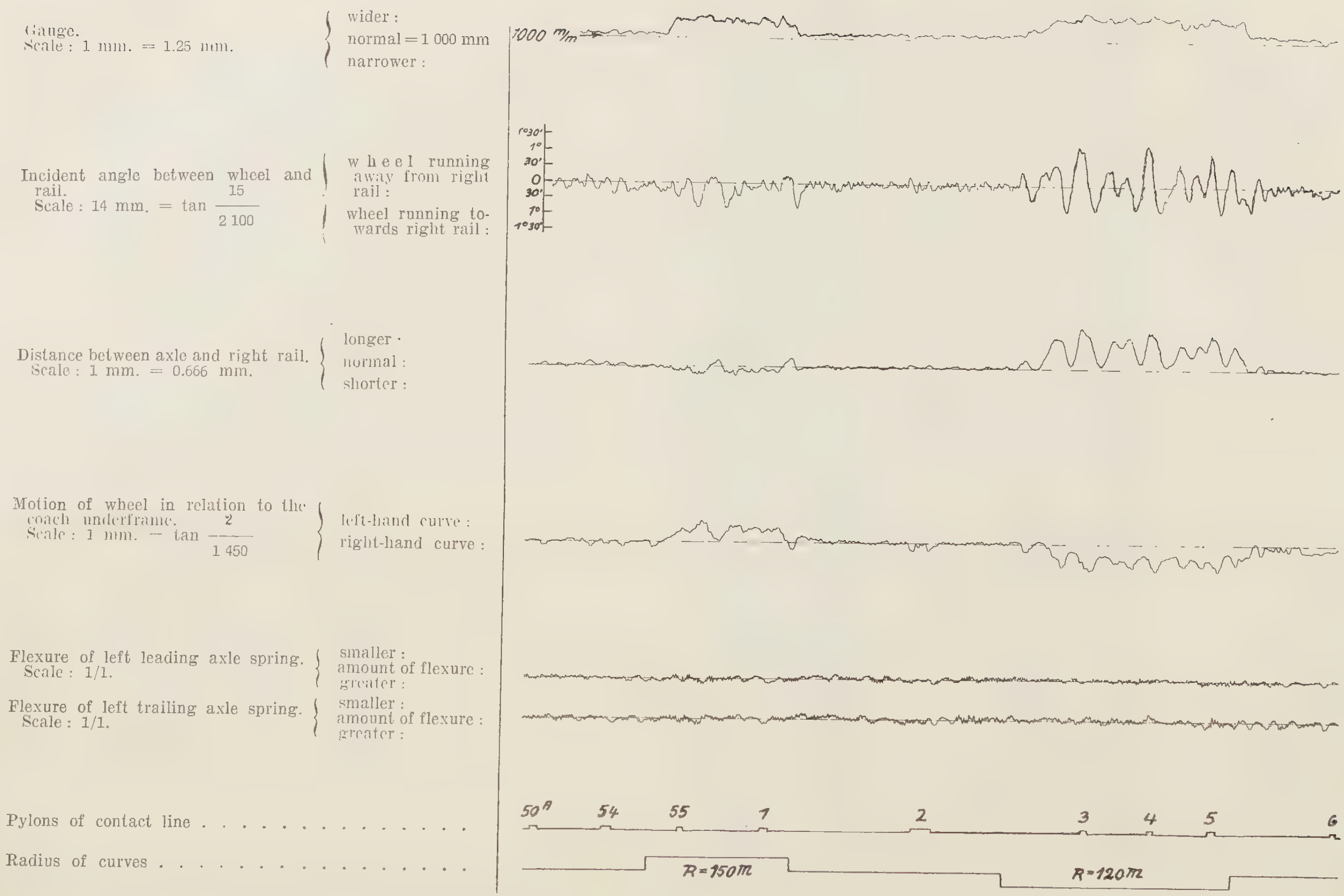


Fig. 14. — Diagrams taken on Gais-Gaiserau run; coach No. 152 of the St. Gallen-Gais-Appenzell Railway (steered axles of the Klose system); measuring axis at the front; July 11, 1934.

(See *Note*, fig. 9.)

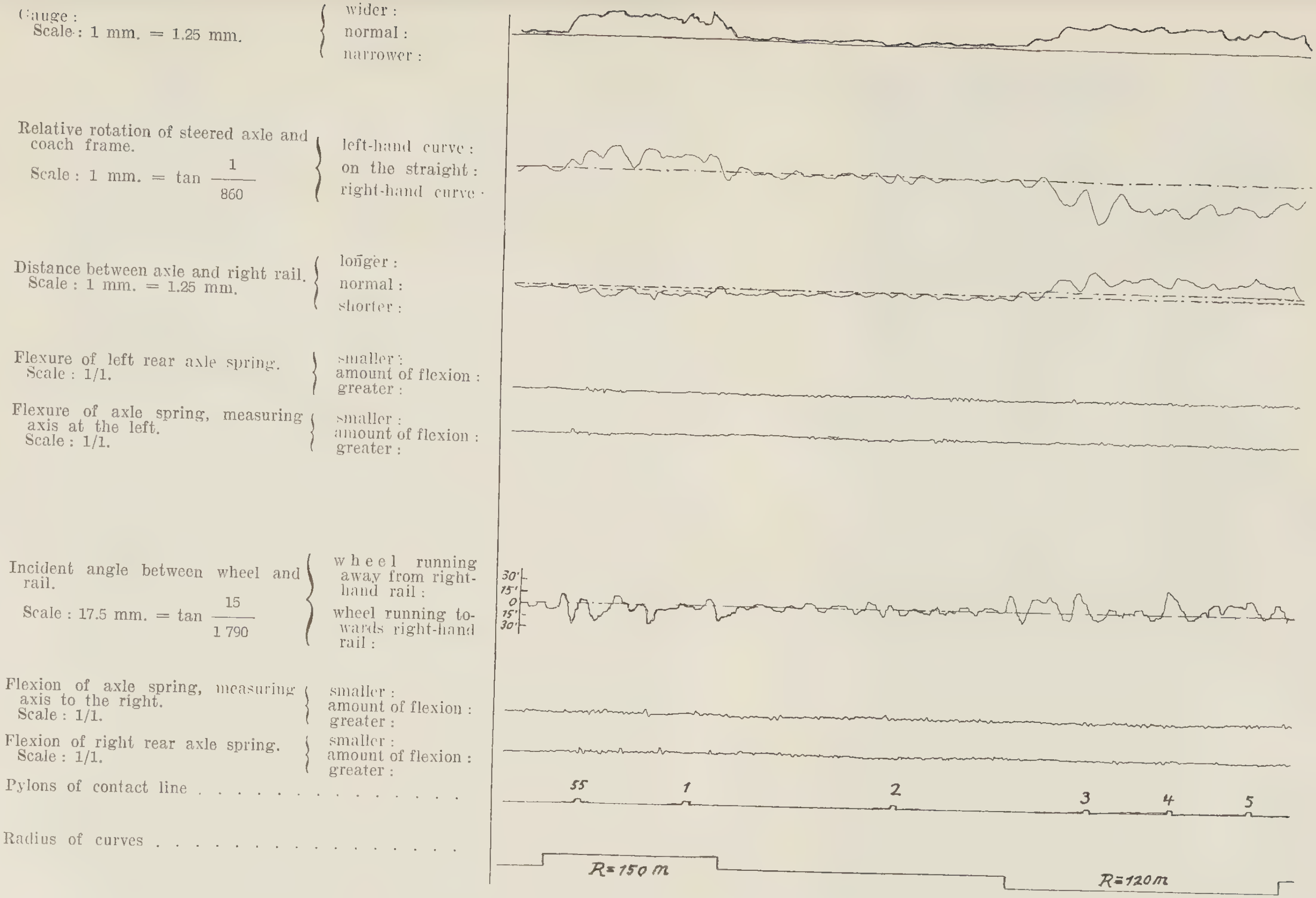


Fig. 15. — Diagrams taken on Gais-Gaiserau run; coach No. 164 of the St. Gallen-Gais-Appenzell Railway; Liechty steered axle; measuring axis at the front; August 1, 1934.
(See *Note*, fig. 9.)

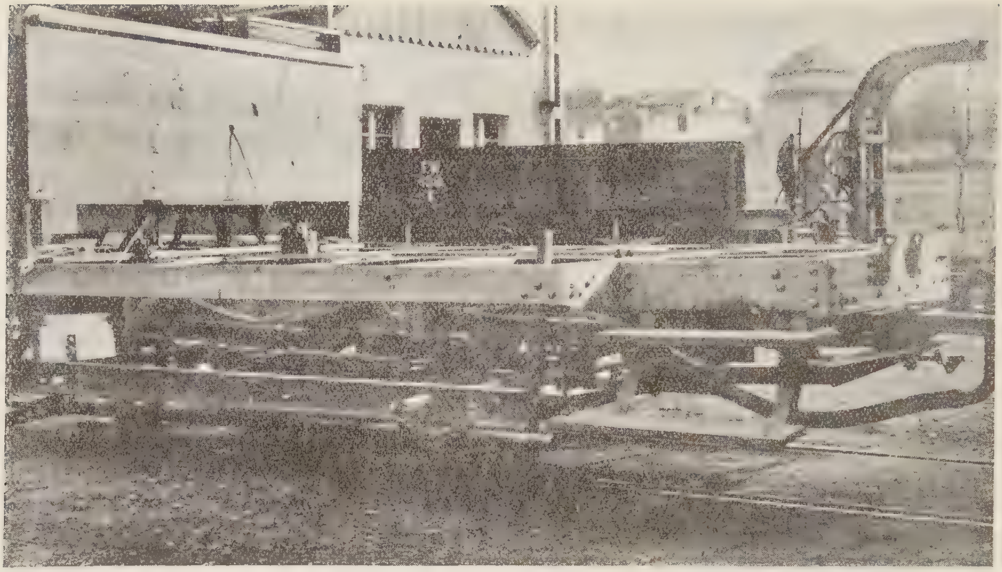


Fig. 16. — Experimental underframe, with two radial axles, Liechty system, of the Frauenfeld-Wil Railway (Switzerland), equipped with the Amsler measuring plant shown in figs. 2 to 5, and 8.

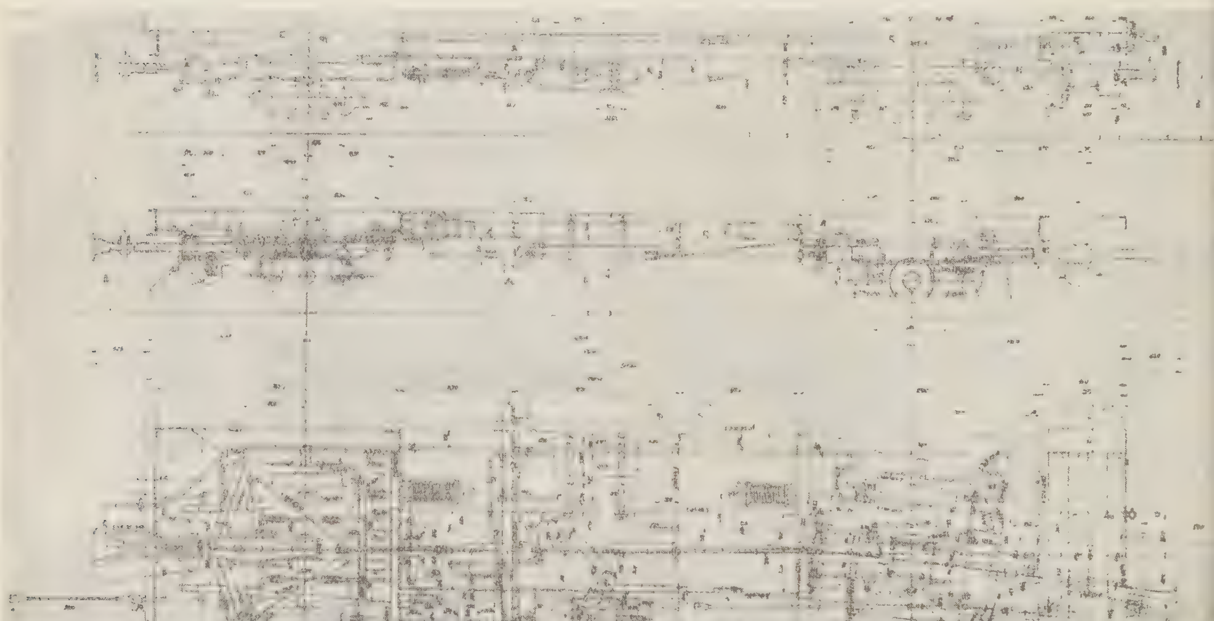


Fig. 17. — Elevation and plan of trailer underframe with two radial axles (bogies with single axle) of fig. 16.

wheels hug the outer rail, and the trailing wheels the inner rail. The centre wheels, having initially a positive angle of incidence, also hug the outer rail and experience a transverse displacement, causing them to realign the steered axles. Owing, however, to the clearance between flanges and rails, the steering effect thus produced is too great, and the leading wheels begin to move away from the outer rail. Directly the angle of incidence of the centre wheels is thus made negative, these wheels move across the track clearance, hug the inner rail and reduce the steering of the other axles so that the original condition is restored. The movement is thus determined by the track clearance and is continually effected by the centre axle. Completely stable guidance on curves is, therefore, impossible with vehicles of this type. Stable running can be effected only by deflections somewhat less than those corresponding to strictly radial control of the steered axles. This applies not only to the Klose system but also to others of similar design.

Against this, figure 15 is a reproduction of a diagram obtained, on the same section of line, with a two-axle truck having exactly the same dimensions, but equipped with steered radial axles of the Liechty system. Figure 16 is a view thereof, and also shows the measuring device in place, figure 17 giving the layout drawing of same. This experiment showed that in this case there was much more accurate control of the axles, and no hunting, such disturbances as were shown being due mainly to track irregularities. The resistance on curves was very small because of the almost radial guiding of the axles. But even with the old three-axle truck built on the Klose system, the resistance is very low, the end wheel sets never bearing on the rails at an appreciable angle.

Summing up, it can be said that the trials have confirmed the theory of the behaviour on curves established by Prof. Heumann, and form a basis of great value for the development of a technically and economically perfect construction of railway vehicles. Also it must be remembered that a reduction of flange friction may be expected to reduce the wear of the rails. Finally, the elimination of great deflecting forces between flanges and rails considerably reduces the stressing of the track at places of unequal elasticity (rail joints), and allows of a truer maintenance of the gauge and alignment, all points which make for smoother running of vehicles.

[625. 162 (73) & 656. 259 (.73)]

Frisco installs retarding barriers.

Push button cut-outs are provided for use during switching moves at installation on 40th street, West Tulsa, Okla.

(Railway Signaling.)

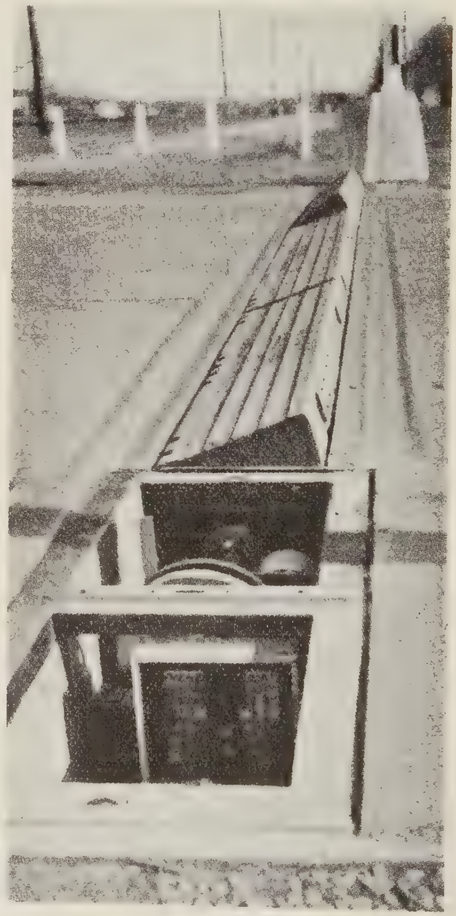
The St. Louis-San Francisco has placed in service two retarding barrier units, supplemented by traffic lights, at a grade crossing in the vicinity of West Tulsa, Okla., on the Southwestern division, extending between Kansas City, Mo., St. Louis, and Tulsa, Okla., and Oklahoma City.

Tracks involved.

The railroad in the vicinity of the crossing consists of a two-track main line, with 8 passenger and 18 freight trains each way daily, with two sidings over the crossing on the north side and another siding turning out from the eastbound main 50 ft. west of the crossing on the south side. A hand-throw crossover between the two main tracks and the lead turnout for the north sidings are located 546 ft. and 1 057 ft., respectively, east of the crossing. The siding south of the main line and the section of the sidings on the north side which are west of the crossing, are used for storage, while the sidings north of the main line are used on the east as team tracks. The two-track main line is signaled with Union Style-S polarized-line-controlled semaphores, installed in 1928. The maximum permissible speeds are 60 m.p.h. for passenger trains and 40 m.p.h. for freight trains.

The highway involved, 40th Street, extends between West Tulsa and Sand Springs, Okla., connecting, approximately 600 ft. south of the crossing, with U. S. Highway 66 between St. Louis, Mo., Tulsa, Okla., and Oklahoma City. Fortieth Street in this vicinity is of concrete, 40 ft. wide. Total highway traffic approximates 2 730 vehicles daily; pedestrian traffic is practically negligible.

Due to the practice of storing cars on the north sidings, and due to a westward



Each of the retarding barrier units has a motor assembly at each end.

curve in 40th Street just north of the tracks, visibility for southbound highway traffic is definitely limited. The view of the tracks is likewise limited for northbound vehicles by buildings and foliage.

Prior to the installation of retarding barriers, the protection at this crossing was given by a watchman by day and a bell at night. The installation of the barriers was made at the request of the Oklahoma State Highway Commission to determine the merits of protection of this type through actual experience.

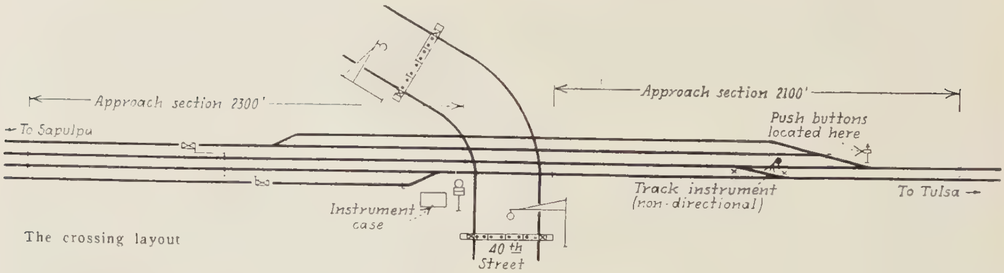
Protection provided.

The recent installation, designed to increase safety without the expense of grade crossing elimination, and especially to protect double-track movements, includes two 35-ft. retarding barrier units, one on either side of the four tracks, 75 ft. from the nearest rail, traffic lights which display red indications when a train enters the approach sections, and a bell located in the southwest corner. Either-direction protection has been provided on each of the main tracks for 2 100 ft. for westbound trains and for 2 300 ft. for eastbound trains. A special stick relay cut-out, operated by push buttons, has been provided for the main-line siding turnout east of the crossing. In addition, operation of the protective devices may be discontinued during switching movements over the south side turnout as long as a member of the train crew depresses a push button, located at the crossing.

Details of equipment.

A general description of this type of retarding barrier, the Auto-Stop, which is manufactured by the Evans Products Company of Detroit, Mich., was given in an article appearing in the May, 1937, is-

Westward train passing crossing. — Retarding barriers in full protective position.



The crossing layout

sue of *Railway Signaling*, while an article appearing in the January, 1937, issue contained a description of typical operating circuits of these devices. At West Tulsa, the unit on each side of the tracks is 35 ft. in length, and is operated by two motors, one on each end, driving two 10-ft. sections in the center and two 7 1/2-ft. sections adjacent to the curb line, the curb having been curved in 2 1/2 ft. on either side from the 40-ft. road width to the 35-ft. barrier length. Each traffic light consists of a unit with two red lenses, with black sheet-steel rectangular-shaped background, suspended at a height of 16 ft. above the roadway on a bracket arm extending from a 25-ft. pole located beside the roadway adjacent to each barrier. A sheet steel sign is mounted on the pole immediately above the foundation; it reads « Automatic RXR Barrier », and has a curved arrow pointing down to the barrier. Standard wood crossbuck signs are located on the right of the road at the crossing on each side of the tracks. The bell is located in the southwest corner, adjacent to the large sheet-steel instrument case housing the control apparatus.

Operation.

Upon the entrance of a train on any approach, the traffic lights display a red indication and the bell rings for approximately 3 sec. before the retarding

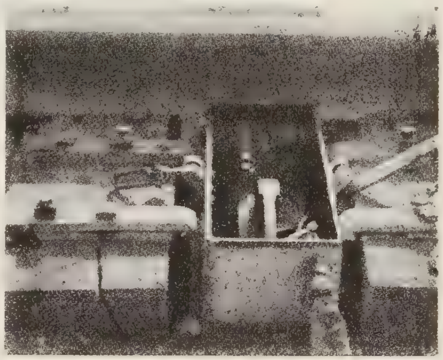
The control relays, etc., are housed in aluminium painted sheet steel case.

barriers start to rise. The barriers are then lifted in approximately 3 sec. to a height of 4 in., where they remain for 10 sec., after which the sections on the side of the road in approach to the crossing rise to a full height of 10 in. in 2 sec. and are locked. The sections of each unit on the off-going side of the road rise only to 6 in., and are not locked at any time. This feature insures that vehicles on the crossing when protection is initiated can leave the crossing merely by continuing over the barrier units on this side, depressing the unit lids to a position flush with the road surface, entirely due to their weight. At all times that the barriers are above the surface of the road, red flashing lights in the face of each section operate. After the train has cleared the crossing, and if no other trains are approaching, the bell is discontinued and the barriers are retracted. When the barriers are again flush with the surface of the road, the red traffic lights are extinguished.

The control of the master crossing relay, which in turn controls the synchronous operation of the protective devices, is effected by the use of two interlocking relays operated by the track relays of the proper sections in approach to the crossing. The cut-out point for each main track is in both cases on the leaving side of the highway, insuring that protection is given until the rear of the train has cleared the road. Track circuits are not provided on the sidings, automatic protection having been provided for main-track movements only.

Switching cut-outs.

When switching movements are made on the westward track and on the turnout for the north sidings in such a manner that protection would be provided when a train movement over the crossing was not contemplated immediately, trainmen are instructed to operate an application push-button mounted in a pedestal case just east of the turnout. Such operation picks up a stick relay, a front contact of which cuts around the contact of the approach relay on the westbound track which is in the controls of the interlocking relay for this track. Trainmen are instructed, upon completion of switching movements, to operate a re-



Track instrument provided for certain switching movements.

lease push-button which restores the control circuits to normal. As an added protection, in case the trainmen neglect to operate the release button, a non-directional track instrument, located 450 ft. west of the turnout, automatically cuts the highway protection back to normal operation, when operated by a train. The rules issued governing operation of these push buttons read as follows :

« General Order No. 6.

« Evans auto-stop in service to protect highway crossing M. P. 427 plus 25 poles, Red Fork, Okla.

« A protection unit is located on each side of the railroad, about 75 ft. from the nearest rail. When a train approaches the highway, these protector units rise above the road level to a height of about 10 in., making a barrier to the passage of automobiles and other vehicles.

The operating battery consists of 16 storage cells on floating charge.

« When train or switch movements are made on the westward main track east of the highway and will not move over the highway and highway traffic is stopped by the protector unit, a member of the train or switch crew should go to the iron relay box locked with a switch lock located near the switch stand on the switch in the westward main track at M. P. 427 plus 17 poles, open the box and push the button marked « Application », and if no other train is approaching the highway crossing, this will lower the barrier, permitting highway traffic to move. When train or switch movements have been completed and a move is to be made over the highway, a member of the train crew should push the button marked « Release », which will raise the protector units, stopping traffic on the highway. »

Likewise, at the crossing proper, while switching movements are being made over the turnout for the south siding, unnecessary delay to highway traffic can be eliminated by a trainman operating a push-botton mounted in a box on the side of the instrument case. This push-

Car leaving crossing, depressing the unlocked off-going barrier section. The right section is locked at the 10-in. height.

button is of the spring-return type and, when depressed, energizes the master crossing relay directly, lowering the barriers and cutting out protection. When it is released, protection is restored to automatic control and if any approach section is occupied, the barriers automatically rise, the application of protection, for subsequent operation of the equipment, passing, in all cases, through the same cycles as described for the initial operation.

Material

The track circuits are each operated by four Edison M-505 cells in multiple, with 4-ohm Model-13 track relays, and track bonds consisting of two No. 8 iron wires with 9/32-in. channel pins. The track leads consist of No. 9 single-conductor mummy-finish underground cables, with Union bootlegs and stranded bond plug-type connectors. A large double-door sheet-steel instrument case houses the control relays, and allied apparatus, all line relays being of the Union DN-11 type, with the exception of the motor control (HDR) relays, which are Adams & Westlake Type 824-2 mercury contact type, and the Model 12 interlocking relays. A slow-acting relay (2.75 sec. slow-release) is used to obtain the delay time between the traffic light and bell operation and the initiation of operation of the barrier, while a DT-10 time-element relay provides the time-delay of the barriers at the « hesitation » point of 4 in.

Power is obtained at the crossing from a commercial source at 110 volts, 60 cycles. Current consumption runs from 60 to 65 kwh. per month. The operating battery consists of 16 Exide DMGO-9 cells floating on an RT-42 rectifier. The control circuits are fed from 5 of the 16 cells floating on an RT-10 rectifier. Two ANL-30 power-off relays, each energized from a 650-v.a. W-20 transformer, are connected in multiple, and, during power outage, transfer all a-c. control circuits to d-c. battery power.

This installation was made by a contractor aided by a supervisor under the direction of the Evans Products Company, with funds supplied by the State of Oklahoma, the maintenance of the device being assumed by the railroad. The total cost of the installation was $ 17 058. The protection was placed in service on July 8, 1937.

[686. 257 (.75)]

Route interlocking on the Baltimore and Ohio Chicago Terminal.

(Railway Age.)

Switches and signals in a route are lined up by operating two push buttons, signal indications are shown in face of buttons, switch indications and track-occupancy indications are shown in track diagram.

At a location near Western avenue and Fourteenth street in Chicago, the Baltimore & Ohio Chicago Terminal (B. & O. C. T.) has installed an extensive new interlocking, a special feature of which is the application of a new type ot route control rather that the conventional lever control. The control machine consists of a panel including an illuminated track diagram. On each of the lines representing the respective tracks, a push button is located at each point where a route may start through the plant. The operation of such a button initiates the setting up of a route, and subsequent operation of the same type of button at the location corresponding to the departure end of the route, completes the manipulation, following which the switches move to the proper positions, and the signal then clears.

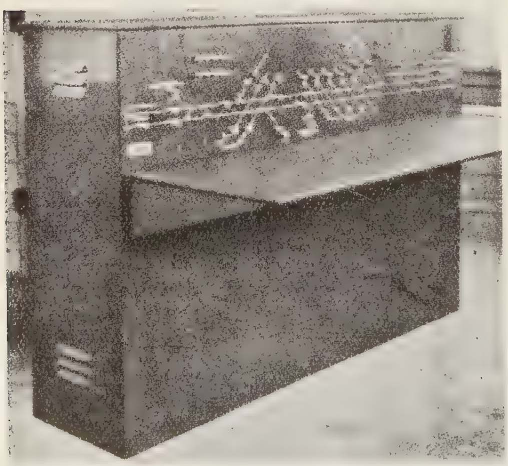


Fig. 1. — The control machine is set at an angle so that the operator has a clear view of the tracks.

Track layout and traffic.

The track layout at this new interlocking includes a junction between a four-track line and a two-track line of the B. & O. C. T., a crossing of a double-track line of the Chicago Junction railway (C. J.) with a double track line of the B. & O. C. T., and also crossings to five switch tracks of the Chicago & North Western (C. & N. W.) whith the double-track line of the B. & O. C. T. The home-signal limits include 6 crossovers, 4 single switches and 33 signals.

The B. & O. C. T. tracks through this interlocking are part of a main lead extending into the Grand Central Terminal, which is located 3.6 miles east of Western avenue. This terminal is used not only by passenger trains of the Baltimore & Ohio, but also by those of the Chicago Great Western, the Pere Marquette and the Soo Line. One or more freight stations of each of these roads are located between Western avenue and the terminal. All of the passenger trains operated in and out of the terminal, as well as switching movements to serve the freight houses and industries in this territory, pass through this interlocking and over the main line of the B. & O. C. T. in the territory between Western avenue and the terminal. Trains of the Baltimore & Ohio and the Pere Marquette use the double-track line diverging to the

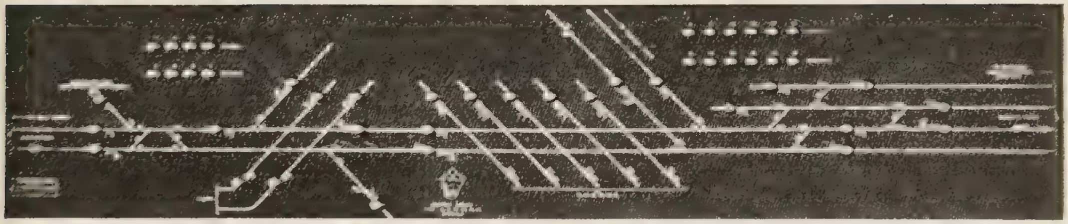


Fig. 2. — The route-control buttons are located in the face of the machine panel in the lines representing the tracks.

south at the Western Avenue plant. Trains of the Chicago Great Western and the Soo Line use the tracks extending westward through the plant.

In periods of normal traffic, as many as 1 200 movements are made over the plant daily. A total of 26 scheduled passenger trains are now operated daily through the new interlocking, and the roads mentioned above also operate

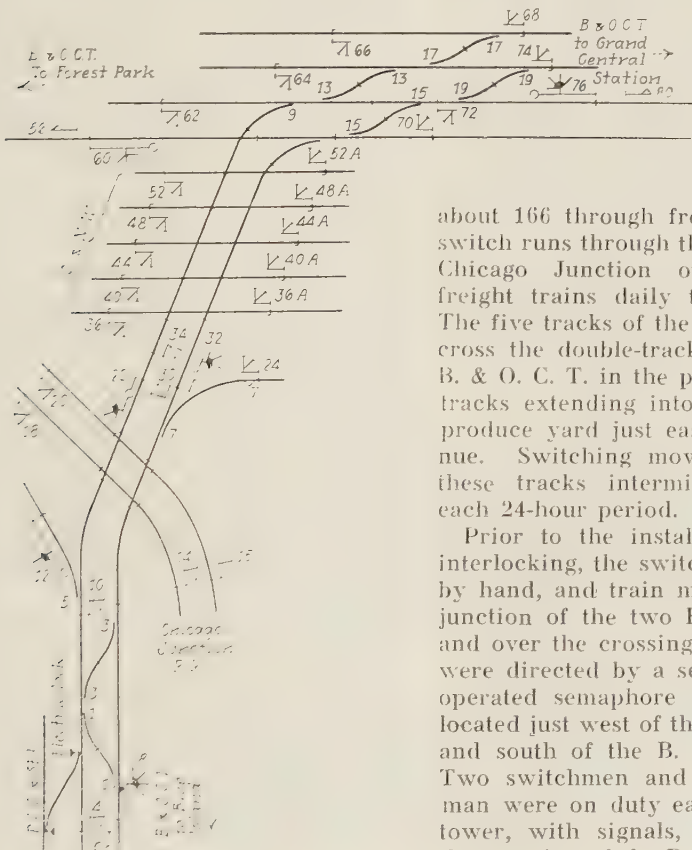


Fig. 3.
The track layout.

about 166 through freight, transfer and switch runs through the plant daily. The Chicago Junction operates about 60 freight trains daily through the plant. The five tracks of the C. & N. W., which cross the double-track main line of the B. & O. C. T. in the plant, are yard lead tracks extending into a large fruit and produce yard just east of Western avenue. Switching moves are made over these tracks intermittently throughout each 24-hour period.

Prior to the installation of the new interlocking, the switches were operated by hand, and train movements over the junction of the two B. & O. C. T. lines and over the crossing of the C. & N. W. were directed by a set of mechanically-operated semaphore signals at a tower located just west of the C. & N. W. tracks and south of the B. & O. C. T. tracks. Two switchmen and one signal towerman were on duty each trick. Another tower, with signals, was in service at the crossing of the B. & O. C. T. and the

C. J. All trains were required to make a safety stop as they approached the crossings, and to get a proper signal before proceeding. The purpose of installing the new interlocking was to operate the switches by power, and to protect the crossings so that the train stops could be eliminated.

This is the first installation of route-control interlocking using equipment manufactured by the Union Switch & Signal Company. The trade name UR has been adopted as descriptive of the term Union Route interlocking. The face of the control panel is made of sheet metal and is 14 in. high and 5 ft. 8 in. long. The machine case is 45 1/4 in. high and 17 in. from front to rear. A desk, supported by brackets, is attached to the front of the machine just below the panel, this desk being 30 in. from the floor, 21 3/8 in. wide and 5 ft. 8 in. long. The machine is located in the new tower on the upper floor, which consists of a single room with windows on all sides so that the leverman has a clear view of the tracks in all directions. The machine is set at an angle so that the leverman can see in all directions, except east, without turning his chair. As the case of the machine is only 45 in. high, he can see over the top without leaving his normal position.

Route-control buttons.

The route-control buttons are located in the face of the machine panel in the lines representing the tracks, each button being mounted in the location corresponding with that of a signal which may govern a train movement to enter the plant or a section of the plant. Only one button is used at each of the locations corresponding to a signal. Such a button can be used either to initiate or to complete the control of the line-up for a route. The first button operated marks the start of the route, and thus determines the signal which will be cleared. The second button establishes the end of the route, or, in other words, the track on which the train will depart from the plant.

When a route is to be set up in the opposite direction over the same line-up of tracks and switches, the same two push buttons are operated in reverse sequence. The operation of the two buttons completes the control for a line-up of a route regardless of the number of switches involved; furthermore, as soon as the switches are positioned and locked, the signal or signals for the route clear, an important point being that not only the signal at the beginning of the route clears, but also the signals within the plant on that route. For example, in lining up a route from signal 8 to departure button 70, the operation of these two buttons lines up the route and causes not only signal 8, but also signal 32, to clear. On the other hand, if the route was to be established only from signal 8 to signal 32, then these two respective buttons would be operated, in which case signal 32 would not be cleared. Thus, routes may be established from signal to signal or through an intermediate signal to the end of the plant.

The buttons operate on the non-stick system of control, so that each button returns to normal position by spring action as soon as the operator removes his finger. The control set-up for a route is automatically cancelled by the passage of a train. Therefore, no further manipulation, comparable to lever restora,-tion, is required of the operator. When it is desired to cancel a route manually, the push button which was operated first is *pulled* toward the operator. A call-on signal is displayed by re-establishing the route control in the same manner, when the route is occupied.

Signal indication on control machine.

Information concerning the aspects being displayed by a signal is indicated in each instance by lamps, which are mounted behind the corresponding push button, and which throw light through a lens located in the center of the button.

Normally the lamps are extinguished. When the first button of a route set-up is operated, the indication lens in that button is illuminated to show red, which indicates that the route set-up is still incomplete and that the signal has not cleared. As soon as the route is complete and the signal clears, the indication in the button changes from a red to a green. This indication burns steadily when a high-speed, medium-speed or slow-speed signal clears, but the indication lamp flashes green when a stop-and-proceed, call-on signal is cleared.

The indication lamp in the button at the leaving end of a route ordinarily remains extinguished, but if an attempt is made to set up a route which is not available, a red light will appear in that button as an indication of improper manipulation. In such a case, both buttons must be *pulled* in order that the controls may be restored to their normal condition.

Special control of C. & N. W. signals.

After the passage of a train on the B. & O. C. T. tracks, it is advantageous that switching movements on any or all of the five C. & N. W. tracks be started at once. In order to facilitate manipulation, one miniature-type, two-position lever was provided for the control of all of the 10 signals on the C. & N. W. tracks. The controls of these signals are non-automatic. Only one track circuit is employed on these C. & N. W. tracks to provide locking to prevent establishing a conflicting route. After these signals have been cleared, they remain so, independent of occupancy of any or all of the tracks on the C. & N. W. With this control arrangement, the C. & N.W. can continue to switch back and forth over the crossing with no further attention on the part of the towerman. When a through train is approaching on a B. & O. C. T. track, the towerman sets the C. & N. W. signals at stop as a warning for the C. & N. W. to clear the home-signal limits as soon as possible.

A situation might arise in which a switch engine, running light or with only a few cars, would approach on one of the C. & N. W. tracks at the same time that another switch engine with a long cut of cars was approaching on another C. & N. W. track. Time might be available for the light engine to move across the plant, but if the drag were allowed to proceed it might interfere with through trains on the other road. In order to meet such circumstances, a separate push-button control is provided for each track on the C. & N. W. If the signals for only a certain track or tracks of the C. & N. W. are to be cleared, the separate push buttons for the corresponding tracks are used, as for example, push buttons 36, 40, 44, 48 and 52.

Route indications.

The entire track arrangement controlled from the UR interlocking panel is indicated by individual white lines representing the tracks. This track layout is on a steel front plate with a dull-black baked enamel background. The steel plate is cut out, and these cut-out places are filled by moulded translucent glass sections to represent the track circuits.

Two lights of different colors, one white and the other red, are located back of each section of track. This makes three indications available, one being the normal unoccupied condition, indicated by no illumination, the second being a white illumination, indicating the complete route as set up through the limits of the interlocking, and the third being a red illumination of those sections as they are occupied by a train as it advances over the route. As the rear of a train clears the various sections of track, the indication on the track automatically becomes normal, without illumination.

Information as to whether each switch is in proper position and locked

is indicated by means of short sections of the track diagram which represent the switch leads. Referring to the illustration of the track diagram, the section of the track line 7N is used to indicate the normal position of switch 7 and likewise section 7R indicates the reverse position. If any switch is not in proper agreement with the route set-up, established by operation of the route-control buttons, the short section of the diagram embracing the switch will remain dark until the switch moves into agreement. Sectional route locking is in effect to lock all functions, such as switches, in advance of a train and in the sections occupied by a train. As the rear of a train clears each track section, the route locking is released in the respective section, so that other routes involving the section released can be lined up.

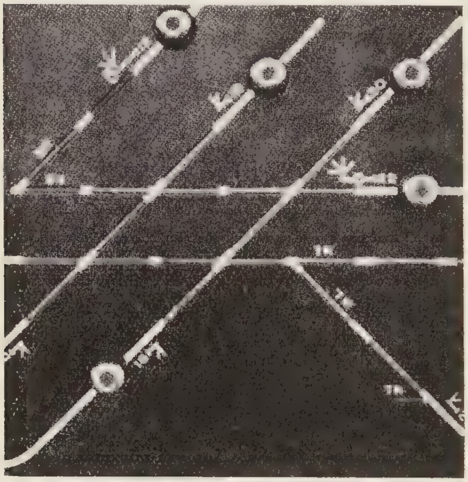


Fig. 4. — Close-up view of small section of the control panel showing the arrangement of moulded translucent glass sections which are illuminated to show indications of track-occupancy and switch positions.

Individual control of switches for test purposes.

When a switch is being tested or adjusted, its operation should be under the direct control of the towerman, entirely separate from the route-control system. Furthermore, when a layer of ice or a block of coal obstructs the operation of a switch point to prevent it from making its complete movement and from being locked up, separate individual control of each switch is necessary in order that the switch may be moved back and forth to crush the ice or coal. For the reasons outlined above, a set of individual switch control buttons is provided. The buttons for the control of the switches at the west end of the plant are located in a group in the upper left-hand section of the control panel, and those for the switches in the remainder of the plant are in a group in the upper right-hand section of the panel. These buttons are not located as a part of the track diagram, because they are not used in normal operation of the route-control system. Two buttons are provided for every switch, one to control the switch to the normal position and the other to the reverse. The circuits are so arranged that any existing set-up or route control must be cancelled before operating switches by means of the individual control. As a result, the operator cannot, inadvertently, by individual control, operate a switch in a route which has been established by route control.

This new Western Avenue interlocking was installed by the railroad's signal department forces, under the general jurisdiction of G. H. Dryden, signal engineer of the Baltimore & Ohio, and under the direct jurisdiction of G. P. Palmer, engineer, maintenance and construction, and C. O. Siefert, signal supervisor, of the B. & O. C. T. J. J. Clancy was the general foreman in charge of construction. The principal items of interlocking materials were furnished by the Union Switch & Signal Company.

MISCELLANEOUS INFORMATION.

[625. 143. 5 (.73) & 656. 281 (.73)]

1. — Derailment on concrete roadbed caused by breaking bolts, Pere Marquette Railroad.

(Railway Age.)

Failure of rail fastenings was responsible for the derailment of a Pere Marquette passenger train on December 17, 1937, while moving over concrete slab-supported track near Beech, Mich. The speed of the train was between 45 and 52 miles per hour and the accident resulted in the injury of 30 passengers, 3 employees off duty and the brakeman of the train.

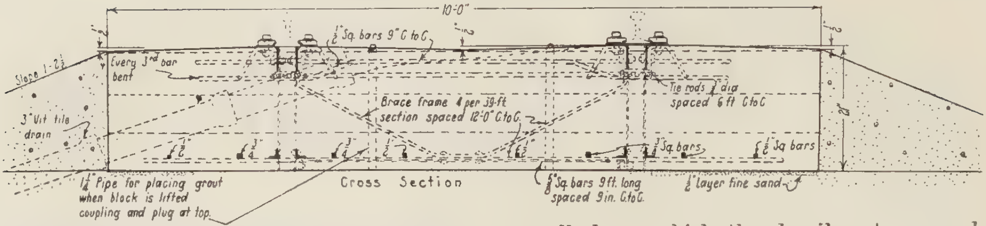
This concrete-supported track was constructed in two units, both in the west-bound track. The first, completed late in 1926, consisting of slabs of rectangular cross-section, has an overall length of one quarter mile, and was described in the *Railway Age* of January 8, 1927, page 174. The second, completed in 1929 over a distance of 400 ft., is of an inverted T-beam slab construction, described in the issue of January 25, 1930, page 236.

The accident occurred on the older installation, in which the rails are held in place by means of clips that are bolted at intervals of 27 in. to steel stirrups embedded in the concrete just below the top of the slabs. These stirrups are rigidly attached to the top chords of steel trusses that comprise the essential element of the longitudinal reinforcement of the slabs.

The bolts used to secure the rail-clips to the stirrups are 3/4 in. in diameter and 2 1/2 in. long. To provide insulation for the rails, a fibre plate 1/8-in. thick by 5 1/4- in. wide was placed beneath the base of each rail for its entire length; fibre plates 1/8-in. thick were placed under each rail-clip and the bolt-hole in the stirrup was bushed with fibre. This entire stretch of concrete slab roadbed is supported on a fill varying from three feet to six feet in height. The track was laid with 90-lb. butt-welded continuous rail.

The point of initial derailment was 731 ft. west of the east end of the concrete roadbed, and following the accident it was found that 261 clip bolts had been broken off on the outer side of the north rail west of the point of initial derailment, allowing the rail to be pushed outward. The concrete roadbed was covered with two inches of ice at the time of the accident.

View of the concrete track support at Beech; the derailment occurred on the older installation of flat-top slabs, seen in the background.



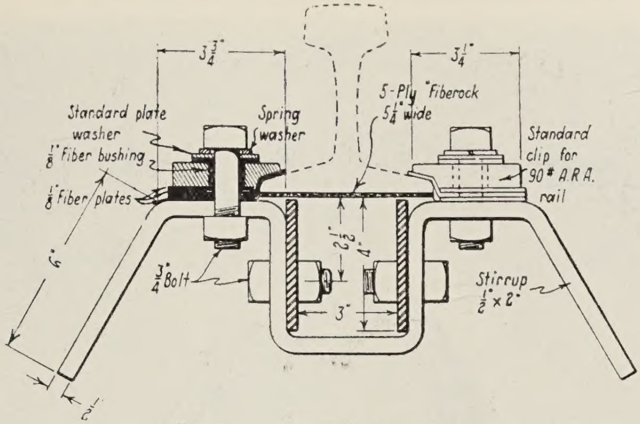
Cross section of the first installation of concrete roadbed, on which the derailment occurred.

During the investigation of the accident by the Bureau of Safety of the Interstate Commerce Commission, the section foreman stated that it had been necessary to renew clip-retaining bolts nearly every day, sometimes as many as 8 or 10 at a time, and the breakage had occurred more often in the winter than in the summer. Most of the breakage occurred in the older section of concrete. When these bolts break they snap off and the clips are sometimes found in the ditch. He said he had had more trouble this year than in previous years on this stretch of track, and thought that all of the bolts are becoming weaker due to getting rusty.

W. Meier, track supervisor, stated that trouble had been experienced with the track on the older section of concrete roadbed due to breakage of the clip bolts at or beneath the surface of the concrete from the time the section of track was placed in operation. A rigid inspection has been maintained, the section foreman having instructions to patrol the section daily. It was his opinion that the derailment was due to failure of the rail fastenings, which permitted the rail to move out sufficiently for the wheels to drop inside the rails. He was unable to state definitely how many anchor bolts were broken monthly but estimated the number at from 8 to 15. After the accident he found that all of the fastenings on the north side of the north rail westward from the point of derailment were broken or out of place.

Showing the type of rail fastening that failed.

R. A. Morrisson, division engineer, stated that the rail was laid perpendicular on a horizontal base and that the movement of engines and trains has a natural tendency to force the rails apart and roll the ball slightly outward. This fact and the small tolerance in the rail fastenings when taken up under traffic permitted the gage to widen uniformly to 4 ft. 9 in. No difficulty has been experienced in maintaining this as normal gage on the concrete roadbed. No trouble has been experienced in the maintenance of the concrete; there has been no settlement or movement of the slab, nor has there been any deterioration in the concrete. Because of the extreme range of temperature in this locality the movement of the rail in expanding and contracting wore the insulation fibre and moved the clips out of normal position. In the winter when the joints were open, battering of the ends of the rails resulted, and this situation continued until the rails were butt-welded to form a continuous rail in 1933 and 1935.



Detail of the rail fastening.

The insulation first placed under the rails was replaced after the first winter with standard insulation fibre, 1/8-in. thick, which has proved satisfactory for insulating purposes. The rail clips and anchor bolts are insulated with the same material. After the derailment, the track for over 500 ft. east of the point of derailment was gaged and the gage ranged from 4 ft. 9 in. to 4 ft. 10 1/2 in.; on the same stretch the track levels varied from 1/8 in. high to 3/8 in. low. He was of the opinion that the wide gage east of the point of derailment developed under the derailed train or the train immediately preceding it, and thought that a factor of considerable importance among the possible causes of derailment was the icy condition caused by the rain and sleet storm of December 14.

While it was evident that spreading of the rails was the immediate cause of derailment, Mr. Morrison felt that the manner in which the north rail was bent around the last bolt that remained in place indicates that some abnormal stress was applied. He suggested also that it might have been caused by swelling of the insulating materials due to their having become saturated and then frozen. The resultant swelling raised the rail clips, permitting the rail to move outward and establish a track gage 1 in. wide. He stated that during 1937 up to date of derailment, 410 anchor bolts were replaced on the concrete roadbed; the number replaced monthly ranged from zero in September to 150 in February.

The conclusion appearing at the end of the report of the Bureau of Safety was that « this derailment was caused by spreading of the track, apparently due to failure of rail fastenings used on track of special construction ».

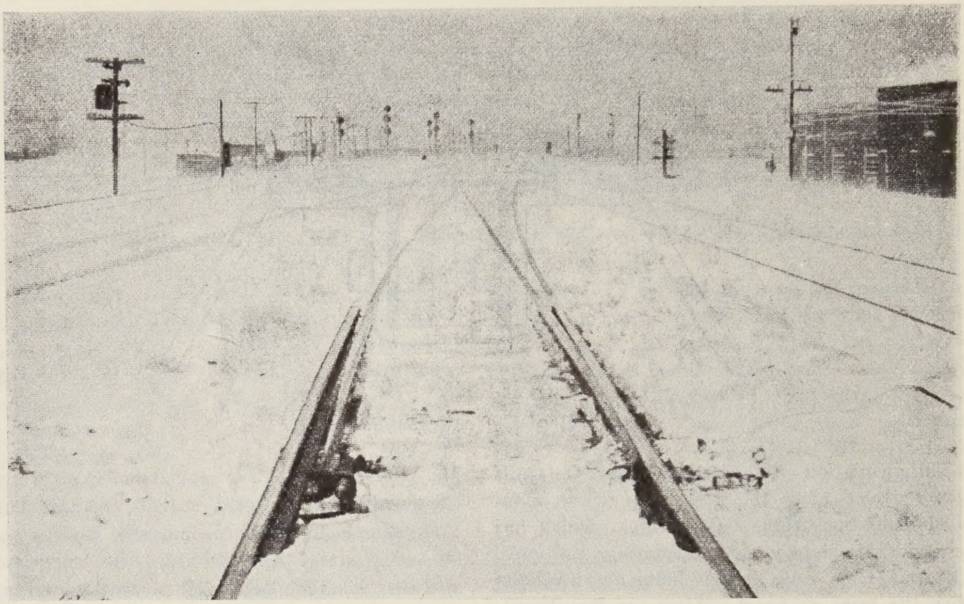
[625. 174 (.73) & 656. 259 (.73)]

2. — Electric switch heaters at Rock Island interlocking prove their value in severe snowstorm,

by LEROY WYANT,

Signal Engineer, Chicago, Rock Island & Pacific, Chicago, Ill.

The Gresham interlocking plant, located near 88th and South Halsted streets, Chicago, is one of the most important on the Chicago, Rock Island & Pacific, controlling a junction of the main line with a heavy traffic suburban line and a crossing with a double-track line used by passenger trains of the Baltimore & Ohio and the Pere Marquette. Traffic



A view of one of the switches at Gresham interlocking during a severe snowstorm illustrating effectiveness of the electric heaters.

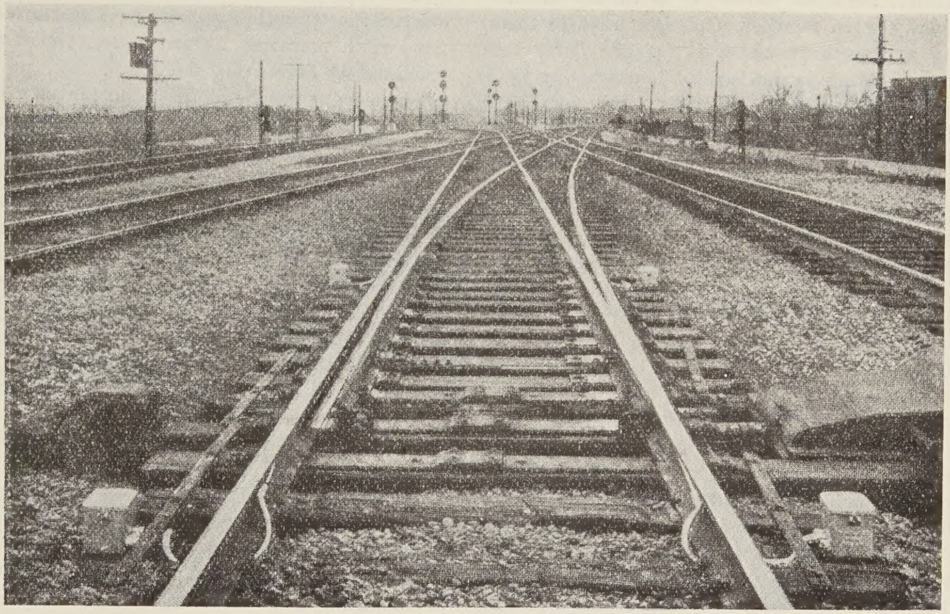
through this plant is heavy, especially from 5.52 a.m. to 7.52 a.m., when 37 trains pass. During the balance of the day from 8 to 15 trains per hour cross this junction.

The tracks lie in open country, with little protection from the wind. In periods of heavy snowfall, this plant has been difficult to keep open. Even with a man stationed at each switch, it remained a difficult job because the passage of trains over a turnout on one route wedged snow and ice about the switch points in such a way that it was impossible to throw the switch until the points were again cleaned out. This condition frequently resulted in serious and costly train delays; a six-minute tie-up on one occasion is reported to have held up 12 trains.

To cope with this situation, the Rock Island, in January, 1938, applied Westinghouse heating elements to the rails of the most important turnouts in the Gresham interlocking; three No. 10 turnouts, two No. 15 turnouts, two No. 10 double slip switches, and one No. 10 movable point frog. In all, 32 heating units were installed.

Construction of heaters.

These heating elements consist essentially of a coiled nickel-chrome wire centered in magnesium oxide and enclosed within a nickel silver tube 9/16 in. in diameter. The active heat-radiating element of nickel-chrome wire is varied in length and in heat output according to the location in which it is applied. For the No. 10 turnouts the wire is 15 ft. long, of which 6 ft., extending from a point slightly in advance of the switch point through the distance in which the switch rail makes contact with the stock rail, is rated at 350 watts per ft., and the other 9 ft. is rated at 125 watts per ft. The element placed on a No. 15 turnout is 18 ft. long, of which the first 7 ft. rates at 350 watts and the remainder at 125 watts per ft. On the movable point frog and on the center points of the slip switches a



The heating units consist of coiled nickel-chrome wire enclosed within a nickel silver tube secured against the web of the rail.

14-ft. unit is doubled back upon itself and rates uniformly throughout at 350 watts per ft.

The heating tube is secured against the web of the rail under the ball by « VV » conduit clamps held by 1/4-in. stove bolts running through holes drilled in the web. The elements are non-rigid. Flattening for special clearances and the making of short-radius bends for the double-back was done in the shops at the time of assembling the complete units.

At either end of the heating elements a brass male connection is silver-soldered, which enters a female connection 1 3/8 in. in diameter and approximately 4 1/8 in. long that completely encloses the terminal contacts. From the heating wire a Monel rod leads to a contact with the terminal brass insert which is seated in a moulded sleeve within the connection. Where the rubber-covered lead leaves the connection, a separate cap nut and rubber gasket insure a water-tight joint.

There are 2 such complete heating units to each turnout, 2 on the movable frog, and 10 on each double slip switch. These units are placed on the gage side of the fixed rails and have proved to be effective in keeping clear of snow an area approximately 7 in. wide on each side of the rail.

A revision of the existing contract under which the local electric utility company supplied power for the Gresham interlocking plant and for the automatic signals and lighting from 91st street (Beverly Hills) to South Chicago, included a provision for serving this installation of switch heaters with 220-volt 3-phase 60-cycle current. The power company installed three 37 1/2 kva. 2300-volt/220-volt transformers to step down the high voltage line current, and the 220-volt power is carried to five control boxes from which it is distributed to the heating elements which are so grouped for control as to balance the three phases of the transformer. In these five control boxes are placed one 60-amp., three 100-amp., and one 200-amp. safety switches, which

permit the snow melters to be turned on manually when weather conditions require them, an arrangement which is feasible here since this location is serviced 24 hours a day by a signal maintainer. Multiple conductor No. 9 Parkway cable sheathed in lead and steel and bedded in the ballast runs from the control boxes to cast iron junction boxes close to the terminals of the heating units, and from these junction boxes rubber-covered leads, protected by 8-ply 1/2-in. « squirt hose » extend the short distance to the heater terminal connections. The total power consumption and heat output of the 32 units is 58.35 kilowatts per hour.

Results satisfactory.

Following their installation early in January these switch heaters had one serious test — during the severe snow storms of April 6, 7 and 8. Nine inches of snow fell on the 6th and four inches more on the 8th, while the temperature reached a minimum of 28 degrees. The heaters were in operation between 16 and 20 hours a day during this period and provided complete protection for the switches on which they were applied, permitting the regular operation of the interlocking plant without any additional men. The only labor required was that of the signal maintainer, who cleared the operation rods and cleaned around the switch machines at convenient times, approximately once every 24 hours. The power consumed during the month from March 25 to April 25, which included these three days, was only 4 133 kilowatts above the previous normal consumption for the equipment served by that contract, creating an additional power cost by reason of the switch heaters of $ 124. The savings in labor costs can only be estimated, but, at the standard figure of « a man per switch per day » during storm periods, the road estimates that the annual savings in labor and materials during a normal winter at the Gresham interlocking, including the cost of train delays, will approach $ 1 500.

The application of these heaters was made by Rock Island forces under the direction of the writer and J. P. Zahnen, signal supervisor. With the exception of the transformer poles and transformers, which were installed by the power company at its expense, the cost of installing the 32 heating units, controls and connections was $ 3 600 for materials and $ 550 for labor, or between $ 225 and $ 250 per switch. Where power circuits are already in, the cost for equipping each switch would be considerably less.